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Smart Charging: An Outlook Towards its Role and Impacts, Enablers, Markets, and the Global Energy System

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Abstract

The push for transport electrification has increased worldwide due to growing concerns about carbon emissions by conventional fossil fuel based vehicles. With the push of transport electrification, the exiting power systems utility grid is also evolving. Electric vehicles (EVs) are becoming popular and gaining the market share in due course of time. The increase in EVs demands more power to charge which results in a significant impact on the utility grid. Dependency on renewable energy sources and the use of local energy storage has increased. Inculcating the incremental addition of EVs and the integration of renewables and local energy storage requires overhauling the planning, monitoring, operation, and maintenance of the power system and its components. Smart charging is an EV charging technique that focusses on reducing the impact of increased power demand and helps in the integration of renewables and local energy storage. Smart charging adds flexibility in the operation of power system components with added functionalities that give augmented monitoring and control to EV users and the power system operator. The goals of smart charging are set to unleash coherency between transport electrification, low-carbon emission generation, and utilization of electricity. This chapter will define the context of "smart" with respect to "smart charging", present an outlook towards its role and impacts on the utility grid and connected entities, and describe the enablers of smart charging, markets, and the operation of the global energy system.

Keywords: Energy system, smart charging, role, market

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1.1 Introduction to Smart Charging

Organizations worldwide are working to ensure the usage of low carbon generating entities meet day-to-day requirements such as power generation and transportation [1, 2]. The use of renewables has helped meet the target in the case of power generation. At the same time, a paradigm shift in the transportation sector with the introduction of electric vehicles (EVs) is evident. This paradigm shift rolled out challenges to the existing power systems due to an increase in the demand for electricity to charge, the use of EVs as distributed energy storage, and regulating the power quality. Smart charging techniques for EVs emerge as a solution to meet the challenges [3].

Smart charging of EVs supports the convergence of EV owners' behavior and requirements, charging, the grid, and all participants involved in the system. Support is provided by various system enablers, which include supporting technologies, policies, and stakeholders. The benefits of smart charging extend to the efficient management of charging during peak and off-peak load hours, increased penetration of renewable energy, reduced transmission losses, economic and technical benefits to users, and much more [1, 4-6]. The smart charging system will unleash more benefits when the users' and service providers' requirements are a defined set of operational standards that are coherently aligned.

The literature presents a broader range of developments in the smart charging systems [5, 7]. Most of the works are on developing algorithms to either maximize, minimize, or compute an optimal parameter to define an efficient working of the smart charging system. Although it is desirable to approach the smart charging system's design to inculcate the interests of all the stakeholders, most of the work did not consider the evolution of the market or the competitiveness of service providers and their outlooks [8].

Cars in general and EVs spend more than 90% of their lifetime parked. The parking period can be used for a variety of purposes, such as local energy storage, mobile energy storage, backup support to homes and buildings, active power support to the utility grid, ancillary services support, and much more. The services rendered by EVs generate income for the EV users as well. An EV can effectively be customized for both mobility and micro-grid connected systems. Apart from the mentioned services, EVs support renewable integration as well. The power generated from renewables is intermittent but attractive as the contribution of carbon emissions in this generation is reduced drastically. The EVs, when used as local energy storage devices, act as a bridge between the utility grid and renewables.

Smart charging also renders a fascinating opportunity to scale-up, improve reliability, automate operation monitoring and control, and overhaul the existing power systems. Although the increased penetration of EVs has a serious impact on the operation of the utility grid, the added potential of EVs with goals of smart charging make the power system flexible at the consumer end, as well as to the power system operator and connected entities. This chapter will focus on the various aspects of dealing with increased penetration of EVs using smart charging. Worldwide, the definition and context of "smart" may vary depending on the requirements of the users. The next subsection will introduce the context of "smart" and describe various approaches to develop a smart system.

1.1.1 Context of SMART

The term "smart" is the most commonly added word to every application, service, and technology in recent times. The context of "smart" varies based on the definition of the manufacturer, user, and the objectives for which the application, services, and technology are developed. Any product that implies making life simpler and better than its previous counterpart is termed as "smart". Hence, defining the context of "smart" is utterly dependent on added functionalities in a product. The functionalities may include intelligence in operation, internet connectivity in devices such as IoT, data-driven operation and analysis, learning capabilities from the deployed environment, communication between devices or entities of a system, or a combination of any or all the mentioned functionalities.

The term "smart" originates from an acronym: Self-Monitoring, Analysis, and Reporting Technology. "Smart" technologies can be broadly categorized in the following ways:

a. Smart automation devices are devices automated by programming and learning data to operate based on an intuitive interface included in the smart automation device. A geyser that operates at a particular interval of time to heat water automatically considering the environment's ambient temperature is an example of a smart automation device.
b. Smart software devices are application based and programmed to perform analytics, display data to the user, request data from the connected subsystems in a system, or any other functionalities for which it is programmed. Such devices mostly require internet connectivity or any

communication link between the connected subsystems. An example of a smart software device is an application installed in a computing system to control and monitor a factory's operation. Smart software devices are considered to be easily scalable and upgradeable.

c. Smart hardware devices, as the name suggests, include remotely connected, monitored, and operated devices. Such devices mostly require a software-based user interface and connectivity using any communication technology to monitor and operate. Smart appliances at homes, such as smart bulbs, are one of the examples of a smart hardware device.
d. Smart computational environment: Computational environment in recent days has upgraded diversely but converges to a common theme of "smart". The environment here refers to all the connected devices or smart devices in a system that give a platform to the user to develop and execute an operation for which the environment is proficient. The operation's development and execution is made possible by establishing necessary communication between each internal device and required external entities. The IBM Cloud, Microsoft Azure, and Google Cloud are examples of a smart computational environment. Users have access to a variety of applications and devices that can be configured as required.

The categorization of "smart" devices is broad and not limited to the types mentioned earlier. Enhancement in existing technologies and new developments have shown vast possibilities of making existing devices smart and accessible. The addition of smart functionalities in any system should increase product capabilities, utilization, reliability, and transcend conventional product boundaries.

The context of smart charging is an amalgamation of all the "smart" technologies. The smart charging infrastructure involves the need of automation devices, software run devices, and supporting software, hardware devices, and the computational environment. Each of the mentioned entities is built with intelligence added by various algorithms that help make relevant decisions and implement them.

Any "smart" system requires proper coordination while developing and operating. The next subsection briefly explains approaches taken by the developers to ensure the addition of functionalities, which make the system smart and reliable to the users and renders market value to the developers.

1.1.2 Approaches

The paradigm of "smart" is relatively novel and rupturing the conventional product developing organization. The conceptualization of connotation demands a systematic approach. The approaches vary based on the utility and target users. A developer takes three different approaches, considering the target, to determine which functionalities are to be added. The first approach is to add smartness to the target applications accessible to users of the device. Adding functionalities to an application so that the users can monitor, control, and execute the workings of a connected system smartly is an example of the first approach.

The second approach adds functionalities to the device instead of the application that connects the user and the device. An example of the second approach is adding sensors and programmed microcontrollers to a device to operate intelligently based on the sensor data and computed parameters. The user interface connected in the second approach can be limited to data visualizations and minimal control operations. The third approach is an amalgamation of both the first and second approaches. Both the target user application and the devices connected are upgraded to develop a smart environment.

The developers of smart charging take the third approach. The third approach ensures that the overall system is intelligent to make decisions even when it is not able to coordinate with the connected devices or software. For example, while in operation, the cable connecting the distribution transformer and the charging station of a smart charging system experience a higher current than the normal value. As per the first approach, the information of fault will be conveyed to the operator of the monitoring station and the fault will continue until the operator signals to shut down the operation. There is a possibility that the cables will be damaged by the time operator responds, the operator did not respond due to negligence, or there was a communication breakdown leading to non-receipt of information at the operator end. If the second approach is taken, although the system will shut down due to fault, the operator will have no information to detect the cause of the fault. However, if the third approach is taken, the operator will get information about the fault and the system will shut down operation on its own. The third approach ensures the safety of the system and saves time working on fault correction.

1.1.3 Contributions

This chapter has described the types of charging followed by the categorization of smart charging, the requirements and components of the smart charging system, the enablers who coherently support the development, operation, and management of the smart charging system, and control architectures developed so far for implementation and integration with the conventional grid. They commenced an outlook on commerce, evolution, and competitiveness in the smart charging system market.

This section is structured to give readers an understanding of the term "smart" and its applicability in an EV charging infrastructure. The first section defines "smart" and explains the context and approaches to adding smartness. The second section deals with different types of charging: *viz.*, uncoordinated, coordinated, and smart. The third and fourth sections describe the impact and requirements of the smart-charging system, respectively. The fifth section defines each smart-charging system's components, followed by a discussion on various control architectures that can be used for smart charging in the sixth section. The commerce and outlook of smart-charging are explored in the seventh section, followed by a conclusion in the eighth section.

1.2 Types of Charging

The charging of EVs needs power from a source. The power source can be the conventional utility grid, local energy storage system, renewable energy systems, or a hybrid system developed by combining any of the sources mentioned. Apart from charging EVs, the power sources also feed load connected and cater services to increase the utility grid's reliability. Charging EVs adds an extra load to the power sources. Three types of charging consider the management and distribution of power due to the addition of load from EV charging are widely discussed in the literature: viz., uncoordinated, coordinated, and smart [9, 10].

1.2.1 Uncoordinated Charging

The utility grid connecting to the load from a power source is designed to meet a particular region's power demand. Further, the utility grid operators perform demand response or load distribution analysis to serve consumers with reliability. If an unprecedented load is added to the utility grid, the possibility of voltage fluctuations and blackouts increases [11]. Uncoordinated charging transpires when the EV's charge is done in the form of unprecedented loads, i.e., the time to charge EVs is not scheduled in coordination with the utility grid [12, 13].

The impact of uncoordinated charging to the utility grid can be described in two ways: increased load demand and change in the shape of load profile. Increased load demand refers to the need for more kilowatts at a particular instant, as noted previously. In contrast, the change in shape of the load profile corresponds to a change in the timing of peak load and off-peak load hours. Literature reports that even a low adoption of EVs could significantly change the load profile and affect electricity infrastructure. The impacts of uncoordinated charging are not limited to the load demand and shape; phase imbalance, power quality issues, such as an increase in total harmonic distortion, increased power loss, line loading, and equipment degradation, such as transformers and circuit breakers, also impact the utility grid [11]. However, the impact of uncoordinated charging is seen on all three segments of the utility grid, namely, generation, transmission, and distribution systems, but the distribution section of the utility grid is the worst affected [14].

1.2.2 Coordinated Charging

Coordinated charging is characterized by charging EVs in coordination with the utility grid. The coordination is required to identify the present condition (load connected) of the grid or power source that will supply the power to charge EVs. The peak load and off-peak load hours of a utility grid vary based on residential, industrial, or commercial regions. In general, for the residential area, the utility grid is in peak load at evening and night hours, while the off-peak load hours are noted during late nights when people sleep. The load demand for an industrial area will depend on the working shifts and operation of factories. For commercial areas, the peak load hours will be at consumer visiting hours, i.e., during the evening. The off-peak load hours will be during the morning [6, 15].

In the case of coordinated charging, based on the regions, the process of charging is scheduled during off-peak load hours. However, it is ensured that EV owners are not barred from the services. The literature is flooded with works done to perform coordinated charging by developing optimizing algorithms, demand response strategy, load scheduling, controllers, dynamic pricing methodology, electricity market operation strategy, and time of use (ToU) [16-22]. Although the works in the literature are diverse, each of them shares the following common goals:

a. The EV owners' need to charge at any time of the day should not be denied, irrespective of the loading in the utility grid

b. The power system operator (PSO) constraints should be coordinated and supported in the quest to charge EVs
c. Necessary support services from the EV owner to the PSO and the PSO to the EV owners should be provided via necessary coordination
d. Increased penetration of local energy storage and renewable energy sources in the utility grid

Coordinated charging of EVs is complicated, expensive, and needs standard infrastructure support for implementations. However, the benefits are immense compared to uncoordinated charging. Coordinated charging helps solve two major issues: first, congestion management, which is defined as an increase in thermal loading in transformers and cables and, second, voltage drops, which are most commonly experienced due to the addition of any unprecedented load, such as EVs [15, 23-25].

The type of charging is also a significant factor to be considered when working with coordinated charging [8, 11]. A fast-charging requires a higher amount of power to be transferred to the EV batteries in a short duration of time. In contrast, in slow charging, the requirement of power is reduced, but time is increased. The ToU and dynamic pricing algorithms are the most commonly presented in the literature to cater to the requirements of power for different charging types. Although coordinated charging solves the basic requirements of charging EVs in consideration to the utility grid's constraints and managing EVs as a load, it fails to be a future proof system where both the EV owner and the PSO are guaranteed an optimized charging process [10, 18].

1.2.3 Smart Charging

Uncoordinated and coordinated charging worked on two different objectives. Uncoordinated charging prioritizes the requirements of EV users. In contrast, coordinated charging tries to optimize utility grid operation considering the grid's requirements and ensuring satisfactory service to the EV users. Although coordinated charging, to some extent, meets the requirement of both the utility grid and EV users, the algorithms and controller developed are inclined to only one segment of operation, the utility grid [9, 26].

The smart charging process, on one hand, lets the EV user decide the priority and, on the other hand, adapts the charging process to meet the requirements of the PSO. For example, suppose a user opts to charge EV during off-peak load hours. In that case, incentives are given in the form of cost reduction in electricity billing. If a user prioritizes to charge rather than considering the grid's condition, especially during peak-load hours, the electricity billing is higher. The user is not barred from getting the desired service, but an optimal solution is met between the EV owner and the PSO [27]. The smart control ensures the charging of batteries in EVs within a given time and considers PSO constraints, such as voltage and frequency regulations. The smart charging's prime concern is to reduce the impact of EV charging and enhance grid reliability and stability. For a better understanding, Figure 1.1 shows the list of expected functionalities to define the level of smartness in the charging system.

The platform for electro-mobility (2016) in the European Union (EU) defines smart charging as: "consist[ing] of adapting EV battery charging patterns in response to market signals, such as time-variable electricity prices or incentive payments, or response to acceptance of the consumer's bid, alone or through aggregation, to sell demand reduction/increase (grid to vehicle) or energy injection (vehicle to grid) in organized electricity markets or for internal portfolio optimization" [26]. Smart charging demands intelligent monitoring, control, and operation [1, 3, 4]. Hence, communication and coordination between the charging infrastructure entities is a must to realize smart charging. In smart charging, the entities are not just a mere power transfer system, but rather a data-rich monitoring system that can monitor, control, coordinate, communicate, forecast, and optimize the operations [2, 7]. A brief description of the various approaches presented in the literature is shown in Figure 1.2.

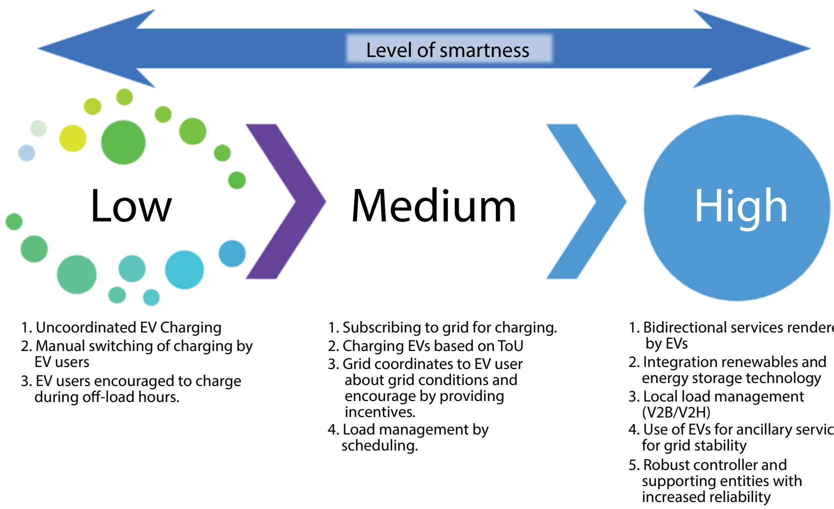

Figure 1.1 Flow diagram to understand and judge the level of smartness based on functionalities.

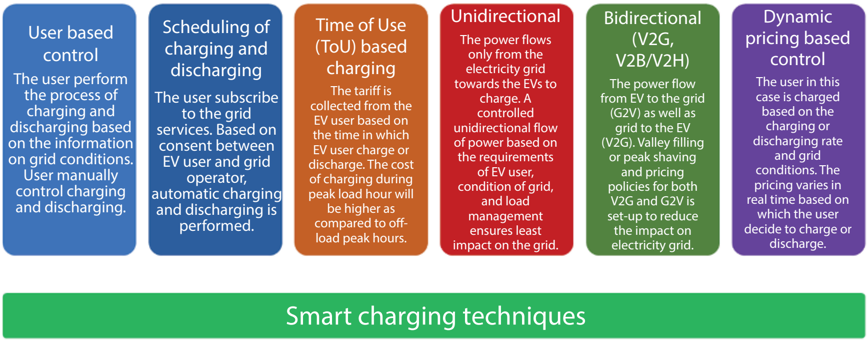

Figure 1.2 A brief on different approaches to smart charging techniques.

The definitions and requirements to call a charging infrastructure smart vary, but all the ideas converge to the following goals:

i. Guaranteed service to the users as required by optimizing all the entities' operations and energy management in the system
ii. Grid-friendly charging of EVs considering peak shaving; grid-friendly charging of EVs is done when the utility grid has required or surplus power (off-peak hours) after meeting the need of a precedented connected load
iii. Renewable integration: the smart charging of EVs should promote the use of renewables. The use of local energy storage systems (ESS) has shown promising results in integrating renewable energy sources to the utility grid. The energy generated from the renewables can be stored in the ESS and supplied to the utility grid when the grid is at stress. EVs act as distributed energy sources by allowing the bidirectional flow of power, hence, EVs can pivot the integration of renewables.
iv. Increase reliability and stability: smart charging monitoring and control algorithms should focus on the utility grid's demand and supply of power. The requirements of all the stakeholders in a power system should be met optimally.

Based on the discussions in the previous paragraphs, a comparison is presented in Table 1.1. Meeting the goals of smart charging is challenging, but its implementation gives an assurance of meeting the specified goals. The impact of smart charging is discussed in the next section.

Table 1.1 A comparison between different types of charging techniques for EVs.

Types of charging	Impact on the grid	Advantages	Disadvantages	Maturity
Uncoordinated	Leads to issues such as increased load demand and change in the shape of load profile, imbalance in phases, and lower power quality	1. It is user friendly and the deployment does not demand any support services or establishment 2. The capital investment cost is the least	1. Increased power losses in transmission line and components 2. Voltage and frequency fluctuations 3. Phase imbalance 4. Power quality issues such as an increase in total harmonic distortion 5. Degradation of transformers and transmission lines	High (Product readily available in the market and used by consumers)

(*Continued*)

Table 1.1 A comparison between different types of charging techniques for EVs. (*Continued*)

Types of charging	Impact on the grid	Advantages	Disadvantages	Maturity
Coordinated	Reduces negative impact by providing ancillary services and frequency control	1. Performs peak shaving and demand response 2. Increased utilization options to EV users such as providing ancillary services and support to the grid by charging and discharging considering grid conditions 3. Load management which reduces power loss and deterioration in the transmission line and transformers 4. Opportunity to engage users in the electricity market	1. The cooperation of EV users is required, which is uncertain 2. The incoming and outgoing of EVs is not predictable, hence relying on EVs for ancillary services and regulation can put the power system at risk 3. The requirement of communication infrastructure will demand huge capital investment 4. The assurance of a positive impact on the electricity grid is missing	Medium (pilot project implementation)

(*Continued*)

Table 1.1 A comparison between different types of charging techniques for EVs. (*Continued*)

Types of charging	Impact on the grid	Advantages	Disadvantages	Maturity
Smart	Helps in peak shaving or valley filling, power management on the grid side and energy management on the EV side, ancillary services, voltage and frequency regulation, improvement in power quality, and renewable energy integration	1. Eases the integration of renewable energy sources in the grid 2. The use of local energy storage adds flexibility to select power source- grid or energy storage for charging 3. Improved grid stability and reliability 4. Control, operation, management, and monitoring of system at ease 5. Promotes usage of EVs due to increased satisfaction of EV owners and PSO	1. Implementation challenge due to complexity 2. Higher risk operation as the operation and control in the infrastructure are dependent on communication systems 3. Demand commitment from both EV users and PSO 4. Variability in market operations interferes with the workings of the infrastructure	Low

1.3 Impact of Smart Charging on Global Energy Systems

The global energy system is characterized by the interconnected electricity grid which comprises of generation, transmission, and distribution systems, as well as the utilization of renewable energy sources. The price of electricity varies for regions around the world. Each country tries to ensure energy security by planning generations within the boundary. In most cases, renewables come to the rescue because recent advancements in local energy storage systems have not increased energy security. EVs are also considered as mobile/local energy storage due to the capacity of batteries used to power the drivetrain. Hence, an increase in the number of EVs in a country has achievable implications to impact the global energy system.

The direction of the flow of power plays a significant role in determining the impact of smart charging. In the case of charging, two types of viz., unidirectional and bidirectional, are described in the literature. In the case of unidirectional, there is a controlled power flow from the utility grid to the EVs to charge, while in bidirectional the power flow is exchanged between EVs and the utility grid [3, 5, 23, 24, 28-31]. When the grid is in peak load hours, controlled power flow from EVs to the utility grid meets the surplus demand and while during off-peak hours, the EVs charge using surplus power in the grid. Note that the charging process is spread out over the day and mostly controlled using algorithms. Of the two, the bidirectional flow of power is found to be better in reducing the impact of uncoordinated charging. A study by the International Renewable Energy Agency (IRENA) states that, in the short term, bidirectional smart charging is able to reduce more curtailment when compared to unidirectional smart charging [32].

Further, CO_2 emissions are also reduced more in the bidirectional case, compared to the unidirectional. The long-term analysis by IRENA is done considering renewables' integration, which includes solar and wind-based isolated systems. For the long-term, a reduction in CO_2 is noticeable in bidirectional viz. when power renewables augment power production as compared to unidirectional. Hence, smart charging promotes the integration of renewables [27, 32].

The impact of smart charging is not limited to supporting the integration renewables, it also helps reduce stress on various equipment in the utility grid's infrastructure. The impact is widely discussed in the subsequent subsections.

1.3.1 On the Grid Side

Smart charging's grid-side infrastructure consists of transmission lines, transformers, substations, connected loads, and the PSO. Uncoordinated charging is widely discussed for various negative impacts it superimposes on the utility grid, such as components (transmission lines, transformers) overloading, power loss, voltage and frequency instability, and increased peak demand [24, 31]. With an increase in load due to the charging of EVs, the utility grid's existing components are overloaded, which increases the demand for generation and transmission. The lifespan of all the components is adversely affected. Increased demand for active power leads to an increase in power loss in the distribution system [23-25]. Further, the financial losses incurred due to the components' damage are mostly not reported in the literature, however, the PSO suffers huge losses due to added investment capital.

Subsection 2.3 described the goals of smart charging. Each goal finds a way to reduce the negative impacts mentioned in the previous paragraph. Smart charging has added the functionality of power management and renewable energy integration. The scheduling of the charging and discharging of EVs over the whole day optimizes power exchange between EVs and the utility grid. Peak load demand is met by using EVs as an energy source. Further, renewable energy's intermittency is curbed by using EVs as energy storage or for charging using renewables. Added benefits of smart charging are the regulation of voltage (by absorbing and supplying reactive power) and frequency (by the exchange of active power), peak shaving and valley filling, and improved utility grid stability [33-35].

1.3.2 On the Demand Side

The demand side comprises of different types of load: residential, commercial, and industrial. The connected loads are vulnerable to power quality changes. The power quality parameters are defined based on voltage and frequency changes and the harmonics in the power supply [31, 36, 37]. With the integration of renewables and EVs in the system, a balance in the whole power system's flow is achieved. Balance reduces voltage surges caused due to surplus power during off-peak load hours and uncoordinated addition of renewables or energy storage. Voltage flickers that damage various equipment, especially in the residential sector, are smoothed. The harmonics are reduced with added control and optimization techniques for smart charging. Power flow management and distribution constrains the phase imbalance on the demand side [38, 39]. Thus, consumers' reliability, on the demand side, is weighted with loads of added benefits from smart charging.

1.3.3 Overall Infrastructure

The infrastructure of the existing utility grid is dominated by outdated equipment to monitor and operate. The implementation of smart charging requires robust communication, controller, and fault tracking systems. A possible solution to meet robustness requires using data-rich monitoring systems to perform necessary forecasting and optimization. Another possibility is upgrading the utility grid by replacing current components with smart components. For example, the conventional transformer can be replaced by a smart transformer. Conventional monitoring systems in substations can be replaced with high-performance systems that can perform monitoring, forecasting, and real-time computation of necessary parameters for fault detection, prevention, and correction. Upgrading the utility grid adds a financial burden to the PSO. Further, renewables integration to the utility grid helps reduce capital expenditure spent on increasing generation [40-43], hence, the PSO prefers to add precision sensors, communication systems, and data storage devices to upgrade rather than replacing the components.

The possibilities of changing infrastructure are immense. Every addition or upgrade to implement smart charging will help make the utility grid infrastructure smart, thereby improving reliability and stability and helping the PSO perform necessary day ahead or month ahead planning to reduce losses, both power and financial.

1.4 Types of Smart Charging

Smart charging is categorized based on the direction of flow of power: unidirectional or bidirectional. Smart unidirectional charging of EVs is implemented in conjunction with the ToU. EV users are encouraged to charge during off-peak load hours. The implementation of unidirectional smart charging is simple and requires the least technically advanced upgrades of existing components but proves to be effective in reducing uncoordinated charging. Further, the charging rate (slow, medium, or fast) in unidirectional charging is also monitored and controlled.

Bidirectional charging is called a "vehicle to everything" or V2X. The V2X is implemented in two standard configurations (shown in the schematic presented in Figure 1.3).

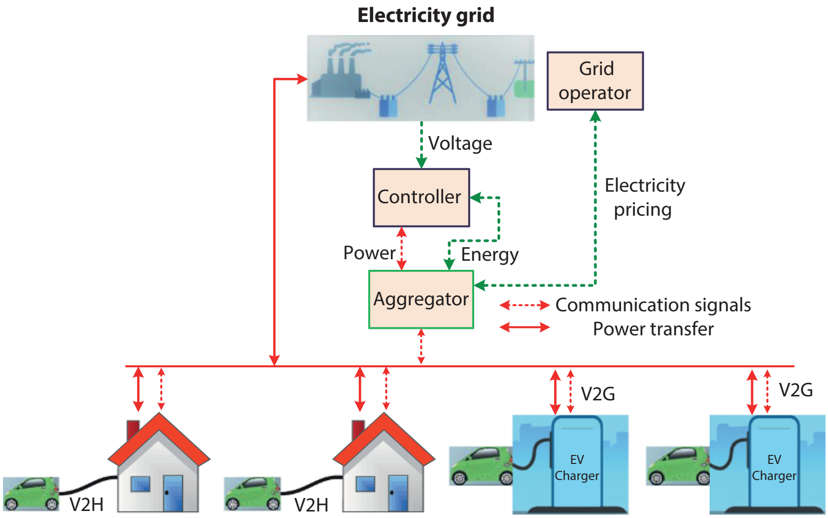

Figure 1.3 A schematic to differentiate V2H/V2B and V2G.

i. Vehicle to the Building (V2B) or Vehicle to Home (V2H):
EV users park EVs in the home, hence, V2B/V2H is prominently used and is a preferred option. The EVs are charged from the supply from the utility grid or a local energy storage device (ESS). The local ESS has energy stored from any renewable energy sources or when the utility grid is in off-peak hours. An additional benefit of V2H/V2B is the use of EV batteries for residential power backup during utility grid outage periods. Further, the simplicity in operation, direct benefits provided to EV users on deploying V2B/V2H, and technology maturity have attracted the market [9, 10, 35, 44].

ii. Vehicle to Grid (V2G):
In V2H/V2B, EVs are used as a residential power backup. However, when the EVs are used to provide support to the grid by discharging during peak load hours and charging during off-peak load hours, it is called V2G. V2G renders a noticeable impact on the grid's operation compared to V2H/V2B [45, 46]. V2G requires intelligent controllers to provide ancillary services such as voltage and frequency control and secondary power reserve. The ToU is also implemented in conjunction with V2G systems [47]. The complexity in the implementation of V2G is higher than V2B/V2H and the technology requires mature and sophisticated solutions to draw market attention.

Table 1.2 Differences between V2B/V2H and V2G systems in smart charging architecture.

Type	Merits	Benefits
V2B/V2H	1. Simple with least capital investment 2. Local control and monitoring 3. Ease in scaling and installment 4. Low power losses and degradation of any power supply equipment	1. EVs can be used as a backup power supply or a generator 2. A step to the development of the micro-grid 3. Reliability of electricity usage 4. EVs acts as mobile energy storage; local energy deficit can be catered to by moving EVs
V2G	1. Give an option to EV user to be a partner to PSO and earn by selling electricity 2. Flexibility in operation 3. Chance to build infrastructure, which will result in increased reliability 4. Large scale control and management 5. If implemented and operated successfully, it promotes EV usage and renewable energy integration	1. EVs, instead of being a burden to the utility grid, coordinate to reduce the impact of the unprecedented load 2. Improved voltage and frequency regulation 3. Increased stability of the grid 4. Demand maturity of technology or sustainable EV market

The difference between different types of smart charging is presented in Table 1.2.

1.5 Entities of a Smart-Charging System

Smart charging systems are evolving. The entities participating in the execution of smart charging algorithms vary based on the countries' organization structure and policy. For example, in India, power transmission is dominated by the Power System Operation Corporation (POSOCO) under the Ministry of Power and state power distribution subsidiaries take care of the distribution systems. Here, the implementation of smart charging would require the involvement of POSOCO and state power distribution subsidiaries. Based on the works presented in the literature, smart charging entities are listed and briefly explained below.

1.5.1 Operators: Generation, Transmission, and Distribution

The power transfer between source and connected loads involves three units of viz.: generation, transmission, and distribution. Smart charging influences all the three units, therefore, they are considered as entities of the system. The addition of EVs as a load to the grid demands more power at the node in which charging takes place. The increase in load is reflected in all segments and generation capacity must be increased to meet the demand. With an increase in the load, transmission line losses, transformers, and connected components increase. Further, deterioration of the distribution transformer's life and the power quality on the distribution side is observed. Hence, the implementation of smart charging requires proper coordination with each unit of power system operators.

Literature reveals the positive impact of smart charging on generation, transmission, and distribution systems. The requirement of additional generation due to the addition of load is substantially reduced in bidirectional smart charging. However, the uncertain availability of EVs is a concern during peak load hours. In the transmission system, smart charging helps improve grid security by performing economic operations and time ahead planning to cater to the requirements by scheduling the charging and discharging of EVs. Improvement in the regulation of voltage, frequency, and load management on the distribution side is one of smart charging's goals [6, 24, 31, 38]. If smart charging is implemented, the assertion of a positive impact on the operators becomes a reality.

1.5.2 Controllers

Controllers are an integral part of smart charging. Smart charging is described in conjunction with power management, optimal control, and operation, satisfying the need for the PSO and EV user. Hence, a robust controller is required to meet the requirements. The controller decides on automatic scheduling, power flow, pricing, and the charging rate of EVs. Two types of controllers are widely discussed in literature: centralized and decentralized [9, 10]. When all the control actions are performed by a single controller connected to all other smart charging system entities, it is called a centralized controller. Alternatively, the distribution of control actions at different segregated units is described as decentralized control.

In decentralized control, a centralized controller is connected to all the decentralized controllers to perform central control actions. Each of the control techniques is described in subsequent sections of this chapter [48].

1.5.3 Aggregators

As the name suggests, aggregators aggregate EVs. Aggregators require group EVs connected at different charging infrastructure areas so that visible, beneficial impacts can be created in the utility grid. The aggregator interface is between the PSO and connected EVs at charging stations, homes, or any location to perform bidirectional or unidirectional charging. Further, the aggregator coordinates with the market to enable the participation of EVs. The aggregator provides the controller with required information to decide whether to enact generation or storage systems and provide ancillary services to the grid [49].

In some cases, aggregators also act as decision-makers. For example, suppose the electricity pricing information is coordinated by the aggregator. In that case, the decision to command the charging locations based on pricing is performed by aggregators [50].

A smart charging system might have one or multiple aggregators. EV owners have options to select their aggregators based on the benefits conferred. The aggregators help the PSO perform day-ahead planning. The planning includes deciding to buy or sell electricity prices; the aggregators' data is sent to the PSO to help with on demand forecasting. The uncertainties involved in EV charging, such as arrival and departure timings, the power required to charge or available to discharge, and preferences of slow or fast charging are also dealt with by the aggregator. The uncertainty management involves the decision to store energy in local ESS during peak load hours and sell to the EV owners at any time. The use of local ESS helps minimalize the impact of charging on the utility grid [51-53]. The information exchanged by the aggregator requires robust communication systems to monitor and operate [54]. The details of the communication systems are explained in the next subsection.

1.5.4 Communication System

The requirements of the communication system are already established based on the description of the above entities. Robust management, control, and operation of smart charging infrastructure depends on an effective communication system. Wired and wireless are two types of communication technologies used in smart charging infrastructure based on the area's demography. The application of wired and wireless communication technology is made in different types of networks, such as a local area network (LAN), home area network (HAN), building area network (BAN), industrial area network (IAN), office area network (OAN), wide area network (WAN), field area network (FAN), and any many more, based on the location and definitions of the deploying organization [10, 13, 49, 54, 55]. A layout of the communication system to exchange information between different entities of smart charging systems is shown in Figure 1.4. All the entities connected by dotted lines depict the communication channels. The channels can be wired or wireless based on the requirements of the communication link to be established [55].

Wired communication technologies, such as optical fiber cable, Ethernet cable, and power line communication (PLC), are suitable for long-distance data exchange. PLC has gained popularity over time. It uses the same power line to share information between connected entities and is more reliable and robust. HomePlug 1.0, HomePlug turbo, HomePlug AV, HD-PLC, and UPA are examples of charging protocols that use PLC [56, 57]. Optical fiber technology is also accessible due to the higher data rates offered.

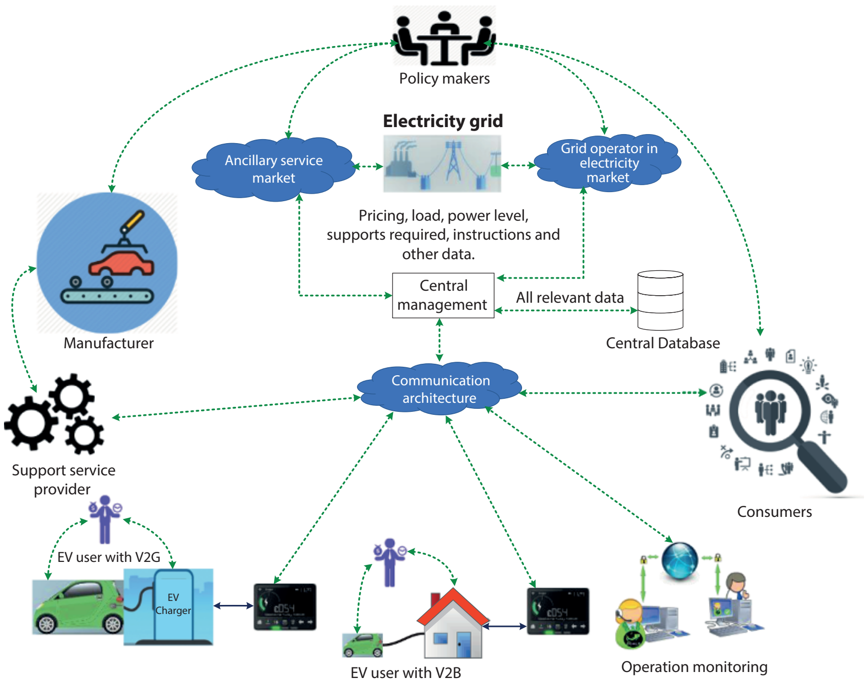

Figure 1.4 Communication between various entities in smart charging infrastructure.

Moreover, a higher transmission range, less impact from electromagnetic interference, and increased reliability due to lower bit error rates are a few other perks to using optical fiber. Apart from PLC and optical fiber, a digital subscriber line (DSL) can also be used, especially in home setups for smart charging. DSL does not require any sperate communication line, but instead uses telephone lines for data exchange [58].

Wireless communication setups are preferred in areas where connected devices are mobile. For example, in charging stations, the incoming and outgoing of EVs are uncertain. Hence, infrastructure developers prefer to use wireless communication technologies. Zigbee, WiFi, cellular network, WiMAX, and satellite networks are popular wireless technologies. The network used the most is called wireless LAN, which is a hierarchical mesh structure for data exchange [54, 58, 59].

Note that more communication channels and entities can be added appropriately.

1.5.5 Stakeholders

The previous subsections described the components which actively participate in the operation and management of smart charging systems. Some entities are involved mostly in the planning stages but are not involved in real-time control. Such entities are manufacturers of various products for the deployment of smart charging, the service providers who perform regular maintenance, and the policymakers who promote the deployment and usage of EVs and the smart charging infrastructure. All are components of the smart charging infrastructure. Each of these is described in the next subsections.

1.5.5.1 Policymakers

Policymakers are individuals or organizations who participate in discussions and policy design processes for smooth and firm implementation of an idea. In the case of smart charging, policymakers focus on increasing EVs utilization in the transportation sector. With increased utilization, the requirements of infrastructure for charging EVs should also be considered. Hence, research and studies are performed to frame policies that converse consumers to think, plan, and use EVs. Policymakers are one of the integral drivers of the paradigm shift in using EVs in the transportation sector.

An example of policy is the Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles (FAME) by the Department of Heavy Industries under the Union Ministry of Heavy Industries and Public

Enterprises. The first phase of FAME, FAME I, was started in 2015 and completed on March 31st, 2019. FAME-II started on April 1st, 2019 and is planned to be completed by March 31st, 2022 [60, 61]. FAME aims to promote eco-friendly vehicles, including electric vehicles and hybrid vehicles, and EV buyers, increasing the demand and production of EVs. The promotion includes providing incentives to both the manufacturer and buyers by reducing taxes and electricity cost. Further, support to set up manufacturing plants for EVs and related technologies are also promoted.

1.5.5.2 Manufacturers

Manufacturers design, develop, and sell the products. In smart charging, the products include EVs, equipment to support power exchange between the grid and EVs, products that are required to develop the communication infrastructure, and the accessories to support the maintenance of all the products and equipment in the smart charging infrastructure. Manufacturers are provided support by policymakers in developing EV infrastructure subsidies for electricity cost, lease of land, and taxes.

1.5.5.3 Service and Support Providers

All the equipment and products used in smart charging need services, such as the internet and electricity, to operate. Further, regular maintenance to reduce the capital cost of replacement due to damage is required. Hence, service and support providers are an integral component. The manufacturer and policymakers consider inputs from service and support providers in both framing policies and manufacturing products. The manufacturer ensures that spare parts of their product are readily available to the support providers. The personnel involved is trained to check and repair by the manufacturers.

1.5.5.4 Consumers

Consumers are the front divers for the implementation of smart charging infrastructure. The demand for EVs and their supporting products and equipment is wholly dependent on consumers' needs. Hence, the manufacturer, policymakers, and service providers do promotions, provide incentives, and assure consumers' maturity and reliability. The consumers also draw constraints, such as charging speed, battery life, and cost of replacing batteries, before buying an EV. If the demand for a product by the consumers' increases, it shows the technology's acceptance [62, 63].

An appropriate business model with policies benefitting all the stakeholders and fulfilling consumers' requirements will be needed for the implementation of smart charging [64].

1.5.6 Market

With the maturity in EV technologies and push of governments worldwide for e-mobility, the EV market has expanded in the past few years. Research to reduce range anxiety, enhance the trust of EV users, reduce the weight of the battery, and establish user-friendly charging stations are a few ways the EV and supporting equipment manufacturers are working to build a momentum of sales in the market. Oil and gas companies are also preparing to operate towards sustainable e-mobility. The smart charging infrastructure market is reported to segmented into EV sales, mobility services, electricity sales to charge EVs, installation and maintenance of charging infrastructure, operation of smart charging stations and the utility grid, and ancillary services [21, 65].

EV sales include the different types of EVs sold in the market, such as consumer vehicles, private vehicles, public transport service vehicles, and heavy vehicles. Mobility services include app development and management to provide services at the users' fingertips, perform data collection and analysis to increase reliability in operation, EV fleet management, booking of slots, and much more. The market keeps evolving with competition between both well-known and emerging companies, each of them seeking to increase their share of the market.

1.6 Enablers of Smart Charging

Smart charging requires enablers to implement it. Consumers and technology are two important enablers. The consumers have a varied aspect of expectations and interpretation for any new technology released in the market. The success and failure of the product depends on the acceptance of consumers. On the other hand, recent times have experienced a rapid transition in technology with new products with desired functionalities released almost daily. The technology required for smart charging should add functionalities that make the system intelligent in operation. Artificial intelligence (AI) and data analytics, popularly called Big Data, are technology enablers [20, 66, 67].

When looking into EV technology, the driving range, charging speed, and availability of charging stations to charge while traveling are the three main constraints for large scale acceptance of electrification of transportation [68]. However, transportation is one of the basic requirements, hence, EV penetration is certain if policymakers' direct policies that incentivize EV users and manufacturers. The flexibility requirements of each individual will be different, but a customer may compromise if usage results in earning [49, 64, 65, 67]. Apart from policymakers, the PSO should also sincerely participate by giving incentives in electricity pricing for EV users prioritizing coordinated and smart charging. A comprehensive approach to promote the use of EVs should be taken with due consideration of the challenges: driving range, charging time, availability of charging stations, the health of EV batteries, and buying cost of EVs and batteries.

The previous sections and subsections have described the requirements of intelligent systems for the deployment of smart charging architectures. The development of intelligent systems demands data. The data in the electricity grid is generally saved in separate database servers which are used for future planning and expansion of the operation [57, 69, 70]. Hence, designing an intelligent system using AI at the electricity grid side can be attempted, but, when a developer looks to develop intelligent systems for the consumers, lack of data is a big challenge. Hence, the digitalization of the complete smart charging infrastructure can be an initial step to plan for smart charging [67].

Digitalization with an assurance of data analytics can help in developing business models, components, software, and connected hardware and an understanding of the expectations of the consumers. The data logged, when analyzed, can reveal various day and night charging patterns, user preferences, the requirement of power to charge, and various ancillary services that can be attached to EVs [71]. Further, the deployment of communication architecture requires decisions to be made on the communication channel to be used. The data analyzed can also help to provide useful insights to decide the data rate. Based on the data rate, communication channels can be selected. Thus, data analytics and AI are important enablers of the smart charging system.

Apart from technologies that add intelligence, billing and payment services are also an essential part of smart charging systems. Advancements in technologies such as blockchain, which provides secured transactions and maintains a ledger, are being utilized. Blockchains have distributed architectures and the operation is based on secured databases that maintain a record of all transactions. The transactions are verified by the users' computational or connecting devices (computer, mobile phone, or any smart devices) called nodes. The technology is preferred to be used in smart charging systems due to security and distributed architecture.

Thus, blockchain technology has also emerged as an enabler in smart charging systems [67, 69].

1.7 Control Architectures

Communication channels interconnect the components in a smart charging system, but the interconnection does not result in a successful operation. The operation requires controllers which either command centrally or are distributed in the subsystems to make decisions. The next subsections will describe different architectures in which the controller is deployed in smart charging systems for smooth monitoring and operation [10, 13, 15, 27, 31, 33, 43].

1.7.1 Centralized

The centralized control system for smart charging systems demands robust communication infrastructure. In a centralized control, necessary data is transmitted from each connected entity to the central controller. The controller performs decision making by determining the optimal solution considering constraints of both the EV user and the utility grid. The solution can be related to the direction of power flow, electricity cost, allowable charging rate, scheduling of charging and discharging of EVs, and power management. The central control, in a few cases, is supported by the necessary algorithms that process the data. The processing of data includes error check, relevant parameter estimations, data storage, and analysis. Nonetheless, the centralized control system determines solutions or makes decisions considering information from the entire system [9, 10]. A schematic of the centralized controller is shown in Figure 1.5. Each of the entities shown connected by dotted lines depicts communication links.

The major drawback of the central controller in a smart charging system is an optimization problem. The optimization problem becomes very large and complex as it involves numerous parameters from different entities. The controller's failure in the centralized control system will result in a complete halt in operation or incur huge losses to the connected components. Further, scalability is another challenge when the optimization problem exceeds the constraints, such as the maximum number of EVs or charging stations [72-74]. The drawbacks of the centralized controller are outfitted by adopting hierarchical control architecture. Several controllers are deployed to administer a particular function. In contrast, the central controller is given the responsibility to monitor and perform load demand

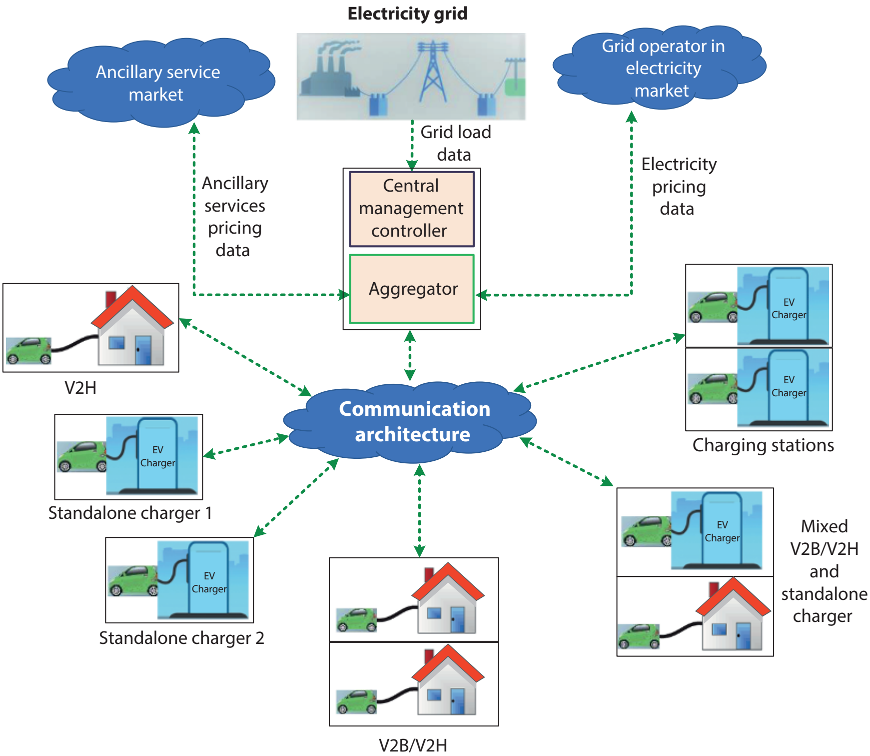

Figure 1.5 Schematic of centralized controller in smart charging architecture.

response. The hierarchical architecture resulted in reduced computational requirements [75, 76]. However, the risk of a negative impact on the smart charging system due to centralized control is not largely reduced.

1.7.2 Decentralized

Decentralized control, contrary to centralized, has distributed control and optimization modules. Charging of EVs takes place spatially in a distributed manner. Hence, the planning of decentralized control in smart charging systems is considered to be safe and reliable. In decentralized control, decision making takes place locally, where the EV charging takes place. The requirement of extensive and reliable communication systems, large and complete optimization, and the risk of damage due to a controller's incorrect decision is readily reduced [74, 77]. The only challenge is performing load management. The data exchange between the utility grid and EV users still demands communication systems. The schematic of

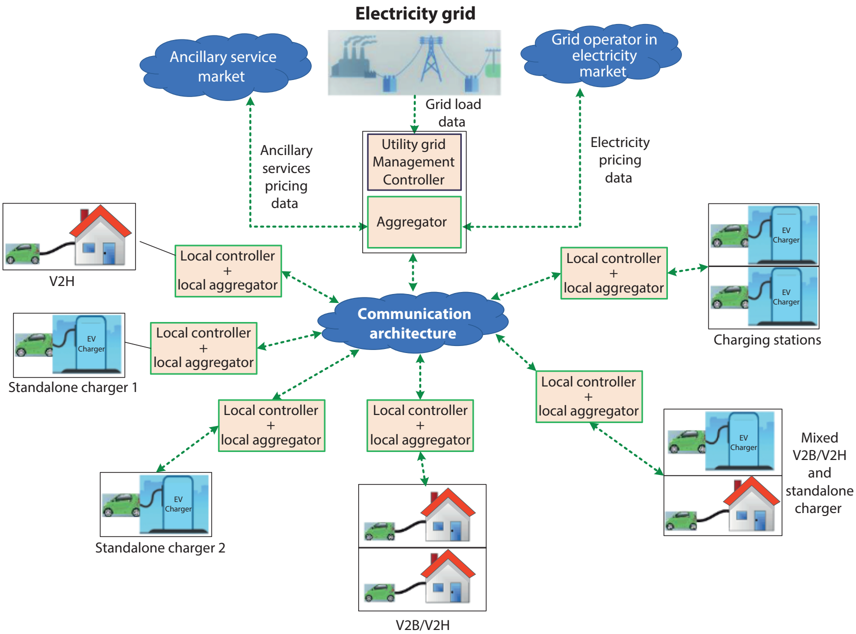

Figure 1.6 Schematic of decentralized controller in smart charging architecture.

decentralized control is shown in Figure 1.6. Each entity has a local level controller and aggregator that are connected to a central controller. The distribution of tasks assigned to each local controller reduces the burden of the central controller to a large extent as compared to the centralized controller scheme.

The simplicity in the implementation of the decentralized controller is leading to an increase in demand. Further, the coherency, like EV operation (spatially distributed), reduces deployment complexity. Further, decentralized control architectures are seemingly practical and scalable, considering their computational complexity [78].

Table 1.3 briefly presents the difference between the control architectures: centralized and decentralized. Based on the merits and demerits, the required architecture can be selected for the design of smart charging systems.

1.7.3 Comments on Suitability

The drawbacks and benefits of centralized and decentralized control architecture infer a requirement for maturity in the smart charging system.

Table 1.3 List of Differences between control architectures in a smart charging system.

Control architecture	Merits	Demerits
Centralized	1. Better voltage and frequency regulation 2. Better utilization of network capacity 3. Can be used with provisions for ancillary services 4. Ease of control and operation inclined towards the PSO	1. System design and deployment are complex 2. Demands huge capital investment in developing robust communication architecture 3. Difficult to scale due to predefined constraints in the optimization problem 4. High computational requirements to process and analyze a large amount of data 5. Robust error correction of data protection is required
Decentralized	1. Ease in the tracking of fault in the system 2. More control to the EV users and higher acceptance rate 3. Less capital investment in deploying communication architecture 4. Easily scalable 5. Ease of renewable energy integration	1. The impact on the utility grid is tough to determine 2. The use of EVs as ancillary services is difficult to implement

During the initial push for smart charging systems for EVs, decentralized architecture looks more acceptable and easier to implement. Further, the demography and topography of the area also significantly impact the selection of control architecture. For an area with higher demography, the decentralized control architecture will resemble centralized control.

For example, consider a densely populated building where the people reside on multiple floors. The parking spot where the charging or discharging of EVs will occur is obviously very compact. Hence, a single controller will be making decisions for multiple EVs. Assume another scenario where the buildings are spatially distributed and the number of persons living in each building is less than the previous scenario. In the second scenario, the parking spot where the charging or discharging of EVs occurs will also not be dense, so single controller can make decisions for multiple buildings. Hence, the demography of an area plays a critical role. On the other side, when topography is looked into, the decentralized controller is preferred, practically, for hilly or mountainous regions. The deployment of communication systems for hilly regions is challenging compared to the plane area.

1.8 Outlook towards Smart Charging

EVs are looked upon as a key to unleashing the potential of clean transportation and low-carbon emission electricity. The push for electrification of the transport sector has brought changes in the operations of current utility grids with a rise in the integration of renewable energy sources. Renewable energy sources are spatially distributed in nature; EVs' mobility and the capability to smart charge and discharge are seen as impactful in integrating renewables to the grid. The outlook of smart charging infrastructure has a wide perspective, which is drawn based on the geography of the land where the infrastructure will be developed, the system analysis time frame, the focus of the impact study, and the society.

The geography of the land helps decide the type of control architecture to be deployed for smart charging. Apart from control architecture, the availability of renewables is also considered. Consider a remotely located region with hilly terrain. The control architecture for such a region is preferred to be distributed, due to capital investment in developing communication architecture. The availability of renewables introduces another opportunity to develop an isolated grid rather than connecting to a larger grid. Hence, the potential of renewables in generating electricity is analyzed and, if the power generation can meet the load demand, an isolated grid is developed. An isolated grid will have a separate control and communication system whose design and deployment will require less capital investment. Apart from less capital investment, deploying smart charging infrastructure on an isolated generation system will be less complicated, easier to monitor, control, and operate, and have a low risk of losses incurred due to the controller's failure or any fault in the system.

The time frame of analysis is another vital aspect to be considered while planning to deploy a smart charging infrastructure. The time frame can have short term or long-term impact. Short-term impact analysis is helpful in operational planning and to perform upgrading of the system. The local impact and system-wide impact are required to be accessed at a regular interval of time. The impact study can result in invaluable insights that can help increase reliability and long-term sustainability. The integration of renewables and an extension of services provided by EVs, such as peak load management and ancillary services, can be made using time frame analysis [66, 79].

The impact study is not limited to technical analysis and proposed upgrades; social acceptance is another barrier to be considered while pushing the use of EVs in the transportation sector. Social acceptance is dependent on the existing grid infrastructure, services provided, and reliability. The smart charging infrastructure is dependent on electricity to operate and manage. Hence, before planning for shifting towards smart charging, it is essential to build confidence by increasing power reliability with the least outages. A balance between society's interest (subsidized charging cost and support if subscribed to smart charging) and the operators' (profits to hold operation and management of company/organization) of smart charging is required [80, 81]. Policy support worldwide also plays a significant role in the social acceptance of EVs and smart charging. Socio-technical analysis at different time frames and implementing recommendations at regular intervals can facilitate greater business opportunities to both operators and EV users [82].

1.9 Conclusion

Smart charging is supposed to be the future of EV charging. With the visible paradigm shift towards transport electrification, policymakers are framing and modifying existing policies to ensure success in implementation. Although the push of countries around the world is based on the sustainable energy goals of the United Nations, without increasing the generation capacity based on the renewables, it is difficult to harness optimal results for reduced carbon emissions. Further, an increased number of EVs will demand an innovative, intelligent, and robust charging infrastructure. Infrastructure development planning should consider every entity and its interests in the deployment. Power and energy management solutions should reduce the burden of the utility grid as well as ensure that each EV user is not barred from their requirements. The present smart charging systems are developed considering either one of the ideas or technology, such as ToU, V2G, V2B/V2H, for dynamic pricing control. If these technologies or ideas are implemented together, there are chances to satisfy the requirements of each stakeholder, although the optimization problem statement might be very complex.

The complete chapter is briefly described below:

1. The chapter defined the context of "smart", followed by approaches a developer takes to make a system smarter.
2. The context of smart is extended to define an outlook of smart charging and its requirements.
3. The components and enablers are discussed in detail to conceptualize the smart charging architecture.
4. The robust control systems involved in developing smart charging systems are introduced as centralised and decentralised architectures. Discussions are made to enable the reader to decide the topology suitable based on the location's topography.
5. A perspective on the communication between energy market entities, which involves two different ends of the smart charging ecosystem (EV manufacturers and the PSO) is focused on in this chapter.
6. The chapter touches on every aspect of smart charging and extensively disseminates the requirements of both smart charging systems and coordination between entities within.
7. The chapter introduced all the positive and negative aspects of smart charging in detail and paved a way to ideate the design and development of smart charging infrastructure.
8. The impact on the market and global energy systems is also presented so that the design and development processes consider them during planning and deployment.

The outlook presented will motivate the readers to work on practical implementation with reduced assumptions and constraints in the smart charging system.

References

1. T. P. Lyon, M. Michelin, A. Jongejan, and T. Leahy, "Is "smart charging" policy for electric vehicles worthwhile?," *Energy Policy,* vol. 41, pp. 259-268, 2012.

2. M. Van Der Kam, and W. van Sark, “Smart charging of electric vehicles with photovoltaic power and vehicle-to-grid technology in a microgrid; a case study,” *Applied energy,* vol. 152, pp. 20-30, 2015.
3. J. P. Lopes, P. M. R. Almeida, A. M. Silva, and F. J. Soares, “Smart charging strategies for electric vehicles: Enhancing grid performance and maximizing the use of variable renewable energy resources,” 2009.
4. I. Sharma, C. Canizares, and K. Bhattacharya, “Smart charging of PEVs penetrating into residential distribution systems,” *IEEE Transactions on Smart Grid,* vol. 5, no. 3, pp. 1196-1209, 2014.
5. M. G. Vaya, and G. Andersson, “Centralized and decentralized approaches to smart charging of plug-in vehicles.” pp. 1-8.
6. B. Sah, P. Kumar, R. Rayudu, S. K. Bose, and K. P. Inala, “Impact of sampling in the operation of vehicle to grid and its mitigation,” *IEEE Transactions on Industrial Informatics,* vol. 15, no. 7, pp. 3923-3933, 2018.
7. Q. Wang, X. Liu, J. Du, and F. Kong, “Smart charging for electric vehicles: A survey from the algorithmic perspective,” *IEEE Communications Surveys & Tutorials,* vol. 18, no. 2, pp. 1500-1517, 2016.
8. S. Han, S. Han, and K. Sezaki, “Development of an optimal vehicle-to-grid aggregator for frequency regulation,” *IEEE Transactions on smart grid,* vol. 1, no. 1, pp. 65-72, 2010.
9. H. Das, M. Rahman, S. Li, and C. Tan, “Electric vehicles standards, charging infrastructure, and impact on grid integration: A technological review,” *Renewable and Sustainable Energy Reviews,* vol. 120, pp. 109618, 2020.
10. J. García-Villalobos, I. Zamora, J. I. San Martín, F. J. Asensio, and V. Aperribay, “Plug-in electric vehicles in electric distribution networks: A review of smart charging approaches,” *Renewable and Sustainable Energy Reviews,* vol. 38, pp. 717-731, 2014.
11. E. Akhavan-Rezai, M. Shaaban, E. El-Saadany, and A. Zidan, “Uncoordinated charging impacts of electric vehicles on electric distribution grids: Normal and fast charging comparison.” pp. 1-7.
12. M. Muratori, “Impact of uncoordinated plug-in electric vehicle charging on residential power demand,” *Nature Energy,* vol. 3, no. 3, pp. 193-201, 2018.
13. R. A. Verzijlbergh, M. O. Grond, Z. Lukszo, J. G. Slootweg, and M. D. Ilic, “Network impacts and cost savings of controlled EV charging,” *IEEE transactions on Smart Grid,* vol. 3, no. 3, pp. 1203-1212, 2012.
14. R.-C. Leou, C.-L. Su, and C.-N. Lu, “Stochastic analyses of electric vehicle charging impacts on distribution network,” *IEEE Transactions on Power Systems,* vol. 29, no. 3, pp. 1055-1063, 2013.
15. M. Singh, P. Kumar, and I. Kar, “Implementation of vehicle to grid infrastructure using fuzzy logic controller,” *IEEE Transactions on Smart Grid,* vol. 3, no. 1, pp. 565-577, 2012.
16. S. Paudyal, O. Ceylan, B. P. Bhattarai, and K. S. Myers, “Optimal coordinated EV charging with reactive power support in constrained distribution grids.” pp. 1-5.

17. Y. Zhang, H. Yu, C. Huang, W. Zhao, and M. Luo, "Coordination of Electric Vehicles Charging to Maximize Economic Benefits." pp. 508-517.
18. J. Hu, S. You, M. Lind, and J. Østergaard, "Coordinated charging of electric vehicles for congestion prevention in the distribution grid," *IEEE Transactions on Smart Grid,* vol. 5, no. 2, pp. 703-711, 2013.
19. M. F. Shaaban, A. A. Eajal, and E. F. El-Saadany, "Coordinated charging of plug-in hybrid electric vehicles in smart hybrid AC/DC distribution systems," *Renewable Energy,* vol. 82, pp. 92-99, 2015/10/01/, 2015.
20. B. Sah, P. Kumar, and S. K. Bose, "A Fuzzy Logic and Artificial Neural Network-Based Intelligent Controller for a Vehicle-to-Grid System," *IEEE Systems Journal*, 2020.
21. A. S. Masoum, A. Abu-Siada, and S. Islam, "Impact of uncoordinated and coordinated charging of plug-in electric vehicles on substation transformer in smart grid with charging stations." pp. 1-7.
22. A. Dubey, and S. Santoso, "Electric vehicle charging on residential distribution systems: Impacts and mitigations," *IEEE Access,* vol. 3, pp. 1871-1893, 2015.
23. D. Oliveira, A. Z. De Souza, and L. Delboni, "Optimal plug-in hybrid electric vehicles recharge in distribution power systems," *Electric Power Systems Research,* vol. 98, pp. 77-85, 2013.
24. S. Deilami, A. S. Masoum, P. S. Moses, and M. A. Masoum, "Real-time coordination of plug-in electric vehicle charging in smart grids to minimize power losses and improve voltage profile," *IEEE Transactions on Smart Grid,* vol. 2, no. 3, pp. 456-467, 2011.
25. E. Sortomme, M. M. Hindi, S. J. MacPherson, and S. Venkata, "Coordinated charging of plug-in hybrid electric vehicles to minimize distribution system losses," *IEEE transactions on smart grid,* vol. 2, no. 1, pp. 198-205, 2010.
26. Å. L. Sørensen, S. Jiang, B. N. Torsæter, and S. Völler, "Smart ev charging systems for zero emission neighbourhoods," 2018.
27. J. J. A. Saldanha, E. M. Dos Santos, A. P. C. De Mello, and D. P. Bernardon, "Control strategies for smart charging and discharging of plug-in electric vehicles," *Smart Cities Technologies,* vol. 1, 2016.
28. K. Valentine, W. G. Temple, and K. M. Zhang, "Intelligent electric vehicle charging: Rethinking the valley-fill," *Journal of Power Sources,* vol. 196, no. 24, pp. 10717-10726, 2011.
29. A. Zakariazadeh, S. Jadid, and P. Siano, "Multi-objective scheduling of electric vehicles in smart distribution system," *Energy Conversion and Management,* vol. 79, pp. 43-53, 2014.
30. J. P. Lopes, P. R. Almeida, and F. J. Soares, "Using vehicle-to-grid to maximize the integration of intermittent renewable energy resources in islanded electric grids." pp. 290-295.
31. M. Tokudome, K. Tanaka, T. Senjyu, A. Yona, T. Funabashi, and C.-H. Kim, "Frequency and voltage control of small power systems by decentralized controllable loads." pp. 666-671.

32. I. Outlook, "Smart Charging for Electric Vehicles," *Available online:/publications/2019/May/Innovation-Outlook-Smart-Charging (accessed on April 28th 2020)*, 2019.
33. A. Di Giorgio, F. Liberati, and S. Canale, "Electric vehicles charging control in a smart grid: A model predictive control approach," *Control Engineering Practice,* vol. 22, pp. 147-162, 2014.
34. J. Kang, S. J. Duncan, and D. N. Mavris, "Real-time scheduling techniques for electric vehicle charging in support of frequency regulation," *Procedia Computer Science,* vol. 16, pp. 767-775, 2013.
35. H. K. Nguyen, and J. B. Song, "Optimal charging and discharging for multiple PHEVs with demand side management in vehicle-to-building," *Journal of Communications and networks,* vol. 14, no. 6, pp. 662-671, 2012.
36. A. Subramanian, M. Garcia, A. Dominguez-Garcia, D. Callaway, K. Poolla, and P. Varaiya, "Real-time scheduling of deferrable electric loads." pp. 3643-3650.
37. K. Clement-Nyns, E. Haesen, and J. Driesen, "The impact of charging plug-in hybrid electric vehicles on a residential distribution grid," *IEEE Transactions on power systems,* vol. 25, no. 1, pp. 371-380, 2009.
38. P. Richardson, D. Flynn, and A. Keane, "Local versus centralized charging strategies for electric vehicles in low voltage distribution systems," *IEEE Transactions on Smart Grid,* vol. 3, no. 2, pp. 1020-1028, 2012.
39. D. Wu, D. C. Aliprantis, and L. Ying, "Load scheduling and dispatch for aggregators of plug-in electric vehicles," *IEEE Transactions on Smart Grid,* vol. 3, no. 1, pp. 368-376, 2011.
40. C. Luo, Y.-F. Huang, and V. Gupta, "Stochastic dynamic pricing for EV charging stations with renewable integration and energy storage," *IEEE Transactions on Smart Grid,* vol. 9, no. 2, pp. 1494-1505, 2017.
41. M. H. K. Tushar, A. W. Zeineddine, and C. Assi, "Demand-side management by regulating charging and discharging of the EV, ESS, and utilizing renewable energy," *IEEE Transactions on Industrial Informatics,* vol. 14, no. 1, pp. 117-126, 2017.
42. Y. Yang, Q.-S. Jia, G. Deconinck, X. Guan, Z. Qiu, and Z. Hu, "Distributed coordination of EV charging with renewable energy in a microgrid of buildings," *IEEE Transactions on Smart Grid,* vol. 9, no. 6, pp. 6253-6264, 2017.
43. X. Zhu, M. Xia, and H.-D. Chiang, "Coordinated sectional droop charging control for EV aggregator enhancing frequency stability of microgrid with high penetration of renewable energy sources," *Applied Energy,* vol. 210, pp. 936-943, 2018.
44. G. Barone, A. Buonomano, F. Calise, C. Forzano, and A. Palombo, "Building to vehicle to building concept toward a novel zero energy paradigm: Modelling and case studies," *Renewable and Sustainable Energy Reviews,* vol. 101, pp. 625-648, 2019.
45. J. García-Villalobos, I. Zamora, J. San Martín, I. Junquera, and P. Eguía, "Delivering Energy from PEV batteries: V2G, V2B and V2H approaches." pp. 247-15.

46. A. Tchagang, and Y. Yoo, "V2B/V2G on Energy Cost and Battery Degradation under Different Driving Scenarios, Peak Shaving, and Frequency Regulations," *World Electric Vehicle Journal,* vol. 11, no. 1, pp. 14, 2020.
47. Q. Huang, X. Wang, J. Fan, S. Qi, W. Zhang, and C. Zhu, "V2G Optimal Scheduling of Multiple EV Aggregator Based on TOU Electricity Price." pp. 1-6.
48. C. Li, Y. Cao, Y. Kuang, and B. Zhou, "Influences of EVs on Power System by Improving the Microclimate," *Influences of Electric Vehicles on Power System and Key Technologies of Vehicle-to-Grid*, pp. 1-23: Springer, 2016.
49. C. Guille, and G. Gross, "A conceptual framework for the vehicle-to-grid (V2G) implementation," *Energy policy,* vol. 37, no. 11, pp. 4379-4390, 2009.
50. C. Battistelli, L. Baringo, and A. Conejo, "Optimal energy management of small electric energy systems including V2G facilities and renewable energy sources," *Electric Power Systems Research,* vol. 92, pp. 50-59, 2012.
51. C. Pang, P. Dutta, and M. Kezunovic, "BEVs/PHEVs as dispersed energy storage for V2B uses in the smart grid," *IEEE Transactions on smart grid,* vol. 3, no. 1, pp. 473-482, 2011.
52. S. Liu, X. Xie, and L. Yang, "Analysis, Modeling and Implementation of a Switching Bi-Directional Buck-Boost Converter Based on Electric Vehicle Hybrid Energy Storage for V2G System," *IEEE Access,* vol. 8, pp. 65868-65879, 2020.
53. W. Choi, Y. Wu, D. Han, J. Gorman, P. C. Palavicino, W. Lee, and B. Sarlioglu, "Reviews on grid-connected inverter, utility-scaled battery energy storage system, and vehicle-to-grid application-challenges and opportunities." pp. 203-210.
54. K. P. Inala, P. Kumar, and S. K. Bose, "Impact of communication systems on grid node voltage and operation of a vehicle-to-grid controller in a smart-grid scenario," *IET Power Electronics,* vol. 12, no. 13, pp. 3499-3509, 2019.
55. W. Han, and Y. Xiao, "Privacy preservation for V2G networks in smart grid: A survey," *Computer Communications,* vol. 91, pp. 17-28, 2016.
56. C.-s. Park, E. Lee, and S.-k. Park, "Link adaptation layer of HomePlug GreenPHY for V2G communication interface." pp. 572-573.
57. J. Lee, E. Lee, and S. Park, "Coexisting V2G PLC between G3 and HomePlug GP using dual PHY." pp. 620-621.
58. Y. Kabalci, "A survey on smart metering and smart grid communication," *Renewable and Sustainable Energy Reviews,* vol. 57, pp. 302-318, 2016.
59. K. P. Inala, B. Sah, P. Kumar, and S. K. Bose, "Impact of V2G Communication on Grid Node Voltage at Charging Station in a Smart Grid Scenario," *IEEE Systems Journal*, 2020.
60. S. I.-N. Delhi, "Fame-India Scheme—Putting E-Mobility on Road," *Auto Tech Review,* vol. 4, no. 5, pp. 22-27, 2015.
61. A. Harikumar, and P. Thakur, "Assessing the Impact and Cost-Effectiveness of Electric Vehicle Subsidy in India," *Journal of Resources, Energy and Development,* vol. 16, no. 2, pp. 55-66, 2019.

62. S. Küfeoğlu, D. Melchiorre, and K. Kotilainen, "Understanding tariff designs and consumer behaviour to employ electric vehicles for secondary purposes in the United Kingdom," *The Electricity Journal,* vol. 32, no. 6, pp. 1-6, 2019.
63. D. K. Shetty, S. Shetty, L. R. Rodrigues, N. Naik, C. B. Maddodi, N. Malarout, and N. Sooriyaperakasam, "Barriers to widespread adoption of plug-in electric vehicles in emerging Asian markets: An analysis of consumer behavioral attitudes and perceptions," *Cogent Engineering,* vol. 7, no. 1, pp. 1796198, 2020.
64. F. Liao, E. Molin, H. Timmermans, and B. van Wee, "Consumer preferences for business models in electric vehicle adoption," *Transport Policy,* vol. 73, pp. 12-24, 2019.
65. C. Lu, F. Chang, K. Rong, Y. Shi, and X. Yu, "Deprecated in policy, abundant in market? The frugal innovation of Chinese low-speed EV industry," *International Journal of Production Economics,* vol. 225, pp. 107583, 2020.
66. O. Frendo, J. Graf, N. Gaertner, and H. Stuckenschmidt, "Data-driven smart charging for heterogeneous electric vehicle fleets," *Energy and AI*, pp. 100007, 2020.
67. H. ElHusseini, C. Assi, B. Moussa, R. Attallah, and A. Ghrayeb, "Blockchain, AI and Smart Grids: The Three Musketeers to a Decentralized EV Charging Infrastructure," *IEEE Internet of Things Magazine,* vol. 3, no. 2, pp. 24-29, 2020.
68. J. M. Fuller, "Social and municipal influences on electric vehicle purchases," 2019.
69. C. Lazaroiu, and M. Roscia, "New approach for Smart Community Grid through Blockchain and smart charging infrastructure of EVs." pp. 337-341.
70. S. Park, S. Lee, S. Park, and S. Park, "AI-based physical and virtual platform with 5-layered architecture for sustainable smart energy city development," *Sustainability,* vol. 11, no. 16, pp. 4479, 2019.
71. R. Niranjan, "Digitalization for Optimization: Smart Grid operations in Finland," 2019.
72. I. G. Unda, P. Papadopoulos, S. Skarvelis-Kazakos, L. M. Cipcigan, N. Jenkins, and E. Zabala, "Management of electric vehicle battery charging in distribution networks with multi-agent systems," *Electric Power Systems Research,* vol. 110, pp. 172-179, 2014.
73. M. Liu, P. Mcnamara, R. Shorten, and S. Mcloone, "Residential electrical vehicle charging strategies: the good, the bad and the ugly," *Journal of Modern Power Systems and Clean Energy,* vol. 3, no. 2, pp. 190-202, 2015.
74. A. Schuller, "Charging coordination paradigms of electric vehicles," *Plug in Electric Vehicles in Smart Grids*, pp. 1-21: Springer, 2015.
75. F. Ni, L. Yan, K. Wu, M. Shi, J. Zhou, and X. Chen, "Hierarchical Optimization of Electric Vehicle System Charging Plan Based on the Scheduling Priority," *Journal of Circuits, Systems and Computers,* vol. 28, no. 13, pp. 1950221, 2019.
76. D. Wu, N. Radhakrishnan, and S. Huang, "A hierarchical charging control of plug-in electric vehicles with simple flexibility model," *Applied Energy,* vol. 253, pp. 113490, 2019.

77. Z. Ma, "Decentralized Charging Coordination of Large-Population PEVs Under a Hierarchical Structure," *Decentralized Charging Coordination of Large-scale Plug-in Electric Vehicles in Power Systems*, pp. 109-129: Springer, 2020.
78. N. I. Nimalsiri, C. P. Mediwaththe, E. L. Ratnam, M. Shaw, D. B. Smith, and S. K. Halgamuge, "A survey of algorithms for distributed charging control of electric vehicles in smart grid," *IEEE Transactions on Intelligent Transportation Systems*, 2019.
79. O. Frendo, N. Gaertner, and H. Stuckenschmidt, "Real-time smart charging based on precomputed schedules," *IEEE Transactions on Smart Grid,* vol. 10, no. 6, pp. 6921-6932, 2019.
80. B. Feng, Q. Ye, and B. J. Collins, "A dynamic model of electric vehicle adoption: The role of social commerce in new transportation," *Information & Management,* vol. 56, no. 2, pp. 196-212, 2019.
81. W. Li, Z. Lin, H. Zhou, and G. Yan, "Multi-objective optimization for cyber-physical-social systems: A case study of electric vehicles charging and discharging," *IEEE Access,* vol. 7, pp. 76754-76767, 2019.
82. L. Geng, Z. Lu, L. He, J. Zhang, X. Li, and X. Guo, "Smart charging management system for electric vehicles in coupled transportation and power distribution systems," *Energy,* vol. 189, pp. 116275, 2019.