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Smart Charging Strategies for the Changing Grid

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Abstract
Charging of vehicles is an important aspect when planning the electrification of transport. The major reasons to adopt smart charging strategies are to minimize the cost of charging and ensure that charging does not happen during the grid's peak. However, the objectives of smart charging have expanded to include the changing supply side perspectives. With the increasing penetration of renewable energy generation, EV charging can provide grid benefits to support the penetration of renewable energy by acting as a load and as a source of flexibility. Thus, the four major objectives of smart charging are: peak management, green charging, acting as a flexibility resource, and cost optimization. This chapter studies the charging strategies based on vehicle type. Different charging strategies are studied and evaluated against these four objectives. Overall, it is concluded that it is possible that the smart charging strategy for EVs can assist in decarbonization of the grid.

***Keywords*:** Smart charging, EV charging, charging strategies, smart charging approaches

3.1 Introduction

Electrification of transport has been identified as one of the significant factors that would lead to an increase in power demand. The story of Electric Vehicles (EVs) and EV charging is quite old, as they are older than Internal Combustion Engine (ICE) vehicles [1]. The evolution of EVs is inexplicably

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intertwined with the history of ICE, development of road and electric grid infrastructure, and affordability of fossil fuels [2]. There are five crucial decades in the history of electric vehicles, as shown in Figure 3.1. In fact, one of the first sets of vehicles developed by Jedilik and Anderson in 1828-1838 were purely electric vehicles with non-rechargeable batteries [3]. This was also the age of development of the earliest EV charging technologies. It is noteworthy that the first patent was filed for wireless charging of electric vehicles by Hutin and Leblanc in 1894 [4].

However, EV charging lost its prominence soon as the mass production of hybrid electric vehicles started in the USA in 1900-10. Many hybrid cars, such as the ones manufactured by Studebaker and Baker electric, entered the market, but soon lost their steam with the improvement of road infrastructure and the fall of fossil fuel costs. EVs received attention again in the 1960-70s with the introduction of the regenerative braking concept and hybrid vehicles, such as Henney Kilowatt, received attention. Some of these vehicles were hybrids with plug-in charging facilities and there was a need to plan for charging of these vehicles. The origins of research of EV charging can be traced to this time period [1, 2].

EV charging gained wider attention around 1990-2000, as more hybrid and fully electric vehicles were coming into the market. In the USA, the Electric Power Research Institute (EPRI) led standardization efforts and developed the widely acknowledged 'Levels' based classification of charging, which was subsequently codified in the National Electric Code (NEC) under article 625. The first case for the need of smart charging can be correlated with power Levels classification. When the power needed for charging EVs in parking lots was higher than the average load of the buildings, a need arose to control the demand that would arise from charging. As expected, one of the key objectives of smart charging methods is also to control the maximum demand from EV charging and guarantee that all vehicles are getting charged [5].

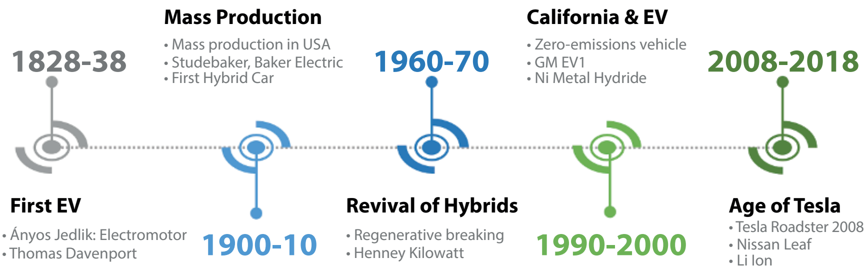

Figure 3.1 Evolution of electric vehicles.

From 2008-2018, the commercialization of Lithium-Ion batteries changed the dynamics surrounding EV charging. These batteries could be charged at faster rates and by nature of design, contained controllable electronic components paving the pathway for smart charging. The bigger question of Vehicle to Grid integration and feeding power back to the grid received attention. In this time period, apart from smart charging, the research focused on the impact of EV charging on the grid, vehicle to home integration, and vehicle to grid power transfer [6].

The objective of smart charging has expanded in recent years, as the adoption of electric vehicles is increasing globally. Electricity generation and distribution are experiencing a fundamental change in the way they operate across the planet. There are two other phenomena apart from the electrification of transportation that are the major drivers of this transformation. These are the increasing penetration of renewable energy and adoption of smart technologies in the electric grid. On top of this, especially developing countries like India, are going to experience substantial levels of increase in energy demand due to the increase in penetration of appliances and universal energy access. These factors have implications for the objectives of smart charging.

- Peak Management: In countries experiencing high growth in electricity consumption and peak demand, EVs can be a contributing factor to further increase peak demand. As peak demand is the basis of planning network expansion and generation capacity planning, this translates to significant investment in the power sector. The primary role of smart charging is to manage peak demand, particularly to avoid additional investments in the distribution grid.
- Green Charging: To ensure clean transportation, it makes logical sense to ensure that EVs are charged from clean energy sources. In some regions like India, where there is a plan for the integration of large-scale Solar PV generation, this implies that the role of smart charging has expanded to ensure the greening of demand.
- Flexible Resource: The flexibility needs of the grid are increasing with the increasing penetration of variable renewable energy. EVs can be an economical source to provide demand-side flexibility and support to the grid as ancillary services. The third objective of smart charging will be to enable EVs to act as a flexible grid resource.

- Optimal Cost: Finally, smart charging still has a role to play in the economics of EV adoption by ensuring that the cost of electricity is optimal for the user and service provider. This objective is relevant, especially in managing the maximum demand at a charging facility or building level.

Smart charging will be the norm of the future and the key question is what major strategies will need to be adopted to meet the four objectives mentioned above. This chapter is a study of various strategies for smart charging with examples of situations to iterate the value for the grid and consumer from smart charging. The major contribution of this chapter will be comprehensive coverage of the four strategies in one study. Apart from this, the research will not be limited to the charging of electric four-wheelers alone. Apart from electric cars, smart charging strategies for electric buses, two-wheelers, three wheelers, and other electric vehicles will also be discussed. This would be a unique value for this work, as there are hardly any studies covering charging aspects of all EV segments comprehensively. Because it is a wide area, bidirectional charging will not be part of the work and the strategies discussed will be only for unidirectional charging.

3.2 Charging Strategy based on Vehicle Type

Charging of vehicles can be done with onboard or off-board chargers. Batteries can be also be removed from the vehicles and charged separately. For vehicles, a quick refueling is possible if the depleted vehicle battery is replaced with a fully charged battery in battery swapping. The application of all these possibilities depends on the type of vehicle, as well as the location of charging. Onboard chargers are suitable for charging overnight and off-board chargers are suited for opportunity charging. For the charging strategy, two possibilities are assumed: overnight charging assumes a charging time between 4-6 hours and opportunity charging takes less than one hour. Opportunity charging of electric cars and buses are presented distinctly. Charging of two and three-wheelers are discussed separately, as they are distinct vehicles.

a. Overnight Charging Design

The most basic type of charging for every electric vehicle is through a low-power onboard or portable charger. Typically, onboard or portable chargers suitable for overnight charging of vehicles are designed so that the charging happens at a slower rate, typically in 6-8 hours. One of the prime

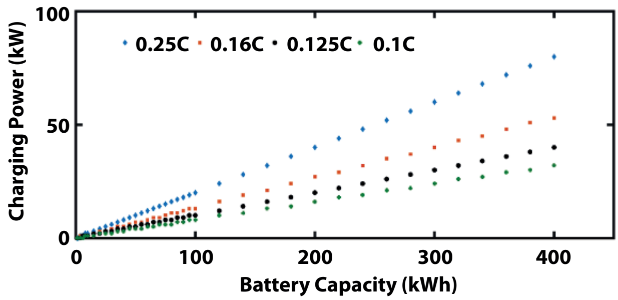

Figure 3.2 Charger power based on battery capacity.

considerations here is to optimize the capacity of the charger to meet the capacity available at residences. In India, typical residential outlets are single-phase 230V, 16 A outlets. In the US, typical residential outlets are single-phase 110V, 20A outlets. This implies that most of the onboard or portable vehicle chargers are designed at output less than 3 kW in India and 2 kW in the US. This makes up Level 1 of charging [7-9].

However, as battery capacity increases, to charge the vehicle in 6-8 hours, the power of the charger needs to increase. A linear graph highlighting battery capacity and charging power is presented in Figure 3.2. To charge the battery of a 60-80 kWh electric car in 6-8 hours, the charger power needed is between 6-11 kW. This brings forth the second level of charging, which is typically understood as 7.4 kW or 11 kW chargers. For buses that have higher capacity battery packs, the charger power needed is much higher. For a 200-300 kW bus battery to charge in 4-6 hours, the charger power needed is between 40-60 kW, hence the most basic charging capacity for a bus could be 50 kW. As a 50 kW charger has an appreciable weight and comes with a safety concern, a common design tendency for buses is to have off-board chargers. The exception to this rule is BYD, one of the largest manufacturers of electric buses globally, designs buses with 43 kW onboard chargers [7-9].

b. Charging Strategy for Two- and Three-Wheelers

Two- and three-wheelers are electric vehicles with batteries under 10 kWh. These are a distinct category of vehicle that do not have active cooling systems. Hence, typically, with plug-in charging, these vehicles are typically charged in 4-6 hours. The charger power for charging two and three-wheeler batteries is presented in Figure 3.3. It can be seen that for two and three-wheelers under 5 kWh batteries, the charger power for overnight charging (4-6 hours) is less than 1 kW. Even for two and three-wheelers

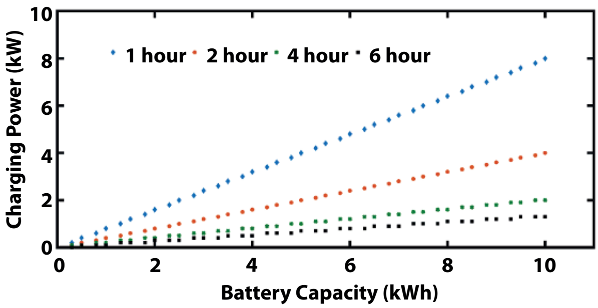

Figure 3.3 Two- and three-wheeler charger power.

with higher capacities that need to be charged in 4-6 hours, the charger power is less than 2 kW. Hence, for these vehicles, Level 1 chargers are under 2 kW [10, 11].

As the batteries cannot be charged faster inside the vehicles and because they are lighter than other vehicles, there is a possibility of removing these batteries from vehicles for charging. If the vehicle batteries are charged separately, outside the vehicle, the charger power needed increases. This type of charging of batteries is classified under battery swapping and, in this case, charging happens in 1-2 hours. However, the weight of the battery needs to be factored in during the design of swapping. It is observed from a market study of electric three-wheelers in India that, typically, swappable batteries are designed hold less than 5 kWh in capacity. To charge a 5 kWh battery in one hour and two hours respectively, the corresponding charger power needed is 2 kW and 4 kW. This makes up Level 2 and 3 charging for swappable batteries [10, 11].

c. Charging Strategy for Opportunity Charging of Electric Car Fleets

For opportunity charging of electric car fleets, charging time under one hour is considered. Taxi fleets could be of distinct battery capacity based on the geography of the market. In most of the popular markets for electric vehicles, such as the Scandinavian nations, the battery capacity of vehicles is high. In cost-sensitive markets, such as India, the vehicles' battery capacity is quite low. Based on the battery capacity and opportunity time interval, the charger power is estimated for charging and presented in Figure 3.4 [7-9].

For electric cars with a battery capacity less than 40 kWh, it is seen that a quick top is possible within 30 minutes with an off-board charger with a capacity of 50 kW. In the case that battery capacities double, the 50 kW charger can still suffice the requirement to top up the battery in an hour.

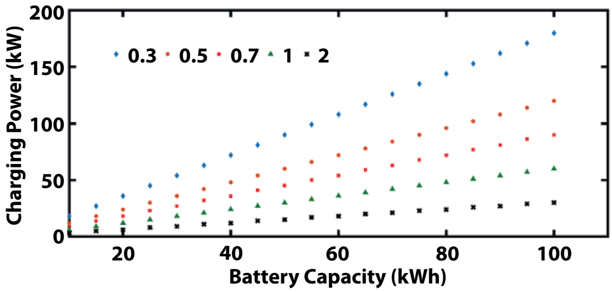

Figure 3.4 Charging power for opportunity charging of electric car fleets.

However, if the time interval of the opportunity charging gets smaller, as the battery capacity increases, a 50 kW charger will not suffice. Hence, the highest level of charger in the market, a 175 kW charger, is studied. It is seen that this charger can provide a quick top-up in 20 minutes for higher capacity battery packs. However, it should be noted that a noticeable percentage of the power drawn will be used for cooling the battery [7-9].

d. Charging Power for Opportunity Charging of Bus Fleets
Charging power for buses is quite high if the time available for charging is quite low. It should be noted that the top-up charge needed at a location is the amount of charge sufficient to reach the next charging location. The most important aspect of planning bus opportunity charging, apart from safety, is to ensure that the service is not impacted because of charging. For high power charging, pantograph systems are typically employed. An estimation of charging power needed to top up thirty percent of the battery capacity is presented in Figure 3.5 [12].

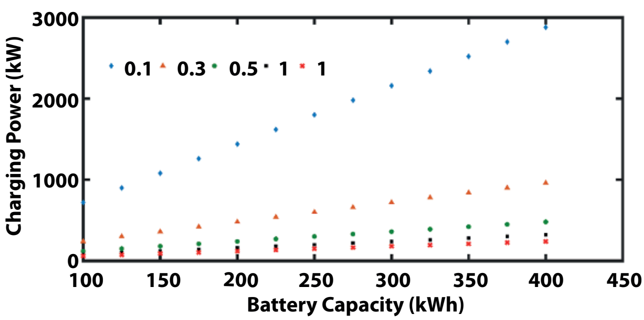

Figure 3.5 Charging power for opportunity charging of electric buses.

The charging power needed for buses could be as high as 500 kW. This implies that the grid impact of these solutions could be very high. Hence, there is a new plan for opportunity charging with solutions such as storage. In Europe, high power bus charging solutions above a certain kW are mandated to have storage. However, as buses operate with a typical schedule, it is possible to plan their overnight and opportunity charging really well. Just like car fleet planning solutions, fleet charging planning solutions are also important for buses. In both cases, maximum demand control is important, which is described in the subsequent section [14, 15].

3.3 Mapping of Charging Strategies

The most important aspect of minimizing the grid impact of charging and ensuring seamless operation with electric vehicle identification and roll-out of suitable charging strategies is important. A few of the strategies that apply for multiple charging possibilities, such as residential charging, workplace charging, fleet charging, and public charging, are described in this section.

a. Timeshift with Time of Use Rates

One of the easiest strategies to adopt for EV charging is shifting the load after peak demand has passed. This is a simple but effective strategy to manage charging without adding additional stress on feeders and distribution transformers during the peak time period. This strategy is apt for charging electric vehicles, such as two-wheelers and four-wheelers, for personal use at home. Apart from this is a strategy that fleet operators can adopt for overnight charging of vehicles. The timesheet strategy there can be implemented with both active and passive control methods. A passive control strategy ideal for this situation is Time of Use charging, a behavioral demand response method. Typically, without the time-of-use rate mechanism, the electricity price will have different tariffs for different time periods of the day. The variation is commonly added as an additional charge in the peak period along with a corresponding rebate during the off-peak period. There could also be a day or night tariff or weekday or weekend tariff. The tariff is designed based on studying the past power usage of the consumer segment [16, 17].

As shown in Figure 3.6, the electricity rate can be designed for EV charging because the rate is low after midnight high during the peak

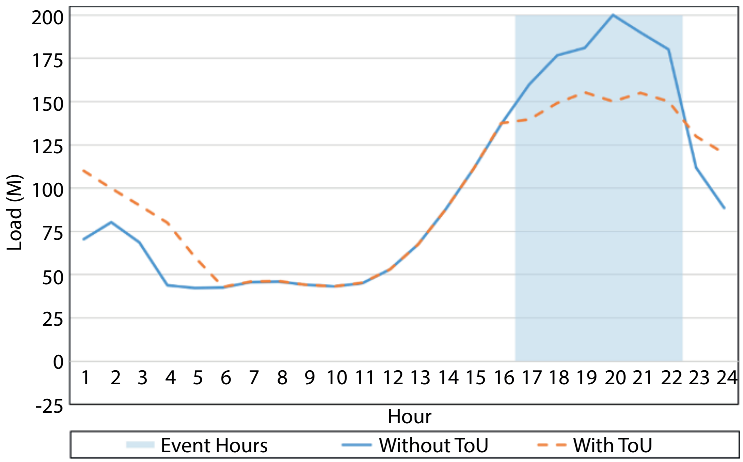

Figure 3.6 Applicable of strategies to control charging at peak demand.

time period in the evening. This is possible in two methods. The first possibility is by converting the residential energy rate into a ToU rate. Alternately, a separate energy rate can be created for EV charging loads. Both methods are popular in the USA. Globally, residential charging is the most popular way for electric vehicle charging. The common parlance for setting the rate for this type of residential charging is to continue the preexisting rate structure or design a different rate structure. In many parts of the world, residential rates are inclining block rates, wherein high energy consumption results in a higher bill. With the additional increase in load from EV charging, such rates are not suitable for residential EV charging. In economies with increased EV penetration, ToU rates are popular for residential EV charging. There are many pilot projects using ToU rates for EV charging. Studies have found that ToU rates are useful in shifting electric vehicle charging from a peak time period to a lean time period. Time of Use rates for electric vehicles are popular in most electric vehicle markets. Under a Time of Use charging rate in Spain, there is a difference of nearly five times between charging in off-peak and peak hours [16-19].

b. Timeshift with Load Cutting

The active charging control strategy can be implemented for shifting the load with an on/off control. In demand response and interruptible load programs are active in many jurisdictions globally. Under an interruptible load program, which is designed as a consumer opt-in program, non-essential loads can be curtailed during grid congestion of a high peak price period. The consumers give the rights to the utility or third party aggregator to curtail their loads. This is a strategy that is currently used to curtail loads during a particular peak load period and can be implemented for EV charging. This would be an important strategy to handle local DT overloading for residential charging.

For the most effective implementation, the time-of-use strategy should be combined with active control measures. This strategy is currently actively employed by many electricity distribution utilities across the world. In the US, the Green Mountain Power Utility provides a technology plus pricing package, where the utility may control the consumer EV charging load and shift it to off-peak hours in the grid. Coupling time of use with an on and off control makes the value proposition better. In these programs to enable the technology, the utilities supply the vehicle chargers to the electric vehicle owner. The EV owner indicates the availability of the vehicle and travel distance. The advances in the internet of things technology have changed the economics of automated charging control solutions [19].

c. Grid Compliant EV Charging with Smart Pricing

Apart from the time of use rates, which are determined by a regulatory process for peak and off-peak demand periods, real-time pricing schemes can be decided. The proliferation of smart metering technology and wide-area monitoring systems enables the design of cost-reflective pricing of electricity and network conditions. Under the "smart" pricing mechanism, the utility sends price signals to consumers. Consumers have the choice to respond to the price signals at the time by starting or stopping charging their vehicles. The objective of this mechanism is to reward customers with lower prices and utilities to benefit the grid congestion situation. This real-time smart pricing system is based on the actual situation in the power grid and could be tied to market prices.

In the UK, a special time-varying rate is offered to electric vehicle consumers, which can promote renewable energy and cater to the flexibility needs of the grid. The technology needed to enable this charging could be a mobile application that can be used in every smart phone and smart meter at the consumer's location. With the shift of energy consumption to periods of low demand and low energy cost, assured savings are given to consumers. In New Zealand, similarly, based on the availability of renewable energy, grid capacity, and cost of power, optimal charging rates are decided for consumers. The consumer only communicates their availability and charging travel time to the utility [19].

d. First-Come, First-Served Charge Management

Shared public charging infrastructure is one cornerstone to assure EV adoption. This charging strategy is suitable for an EV charging facility with multiple chargers. The maximum demand from the charging station is controlled by using a charging control algorithm that selects electric vehicles on a first-come, first-served basis. The simplest design for this charging strategy is where the first arriving EV receives priority for charging power. A first-come, first-served (FCFS) queuing mechanism follows that the first entity that arrives or requests service from a station is the first electric vehicle to be served as shown in Figure 3.7. When the second vehicle arrives, the remaining capacity is allocated to the vehicle and, as the number of vehicles increases, the allocation continues until the capacity is exhausted. When a charging station is fully occupied, the consumer gets added to a waitlist to get in line [24].

The EV may request the amount of energy that is required for charging. The owners can also specify the rate the EV owner will pay. It should be noted that the characteristics of the tariff, that is the change in price as per the tariff rate, which may differ during peak and off-peak demand of the electricity grid, can be incorporated. The energy requirement and price requested by the EV owner are sending this information to the EV charging station in proximity. There can be two different conditions for operation. If the facility has capacity available to ensure the occupancy of the charger, when a customer request arrives, the charge point operator

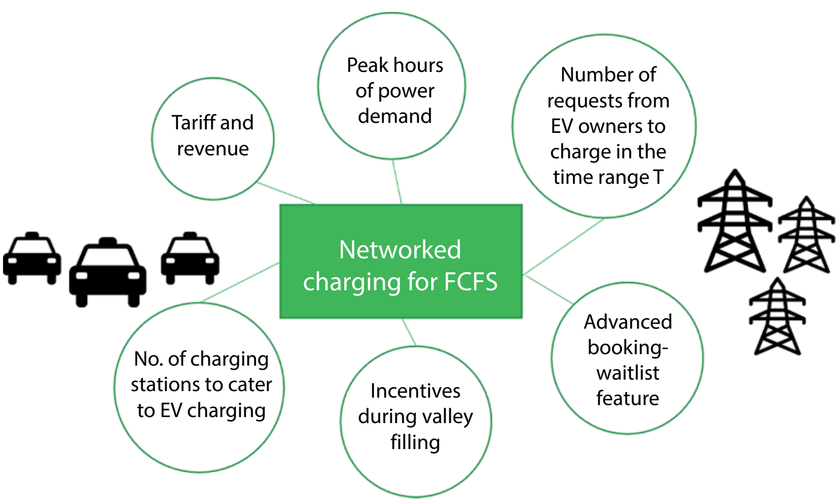

Figure 3.7 First come, first served charging approach.

admits the consumer. For a heavily occupied facility, when a customer arrives, the operator faces a dilemma of allowing the customer in. The EV charging station can also arrange the requests in descending order with respect to profits it can gain by providing charging to the EVs. It provides the charging time, charging price and rate, and duration of charging to the EV owner. The EV charging station would request the EV owner to respond within a certain time limit, depending upon which it will allow the EV to charge or not [24].

e. Coordinated EV Charging

Charging of a few electric vehicles in shared garages or a parking facility can increase the total demand in these structures. This also applies to the parking lots in commercial buildings and multi-unit residential apartment complexes. The building owners can choose to balance the load so that the building's contract demand does not exceed a baseline and continues to enable charging for many vehicles. This strategy can be implemented with and without grid involvement, but the controller is in the charging location. Coordinated charging strategies can be implemented in two ways. Distributed charging, i.e., with decentralized control or, alternately, with centralized control. In distributed charging control strategies, the control is local. It could either be the EV or the facility's owner. In centralized control, typically, a distribution utility or an aggregator monitors and controls the charging or discharging [19, 24].

Coordinated charging is a charging control methodology that can be affected by the power of charging and time of charging. This can be done by a distribution utility, charge point operator, building facility manager, or a home energy management system. This is a charging strategy that was originally used to manage the maximum demand, but it can be used can for grid friendly and grid responsive charging, which can consider the advantages of existing network connections. This can also be integrated into rooftop solar generation in buildings and ensure green charging. This can be effectively rolled out as a demand response and demand flexibility program for electric vehicles [26].

f. Cooperative EV Charging

Cooperative EV charging is one step ahead of coordinated EV charging. The most distinguishing factor of this strategy is demanding aggregators. The EV and charger can negotiate for the charging power and charging time without direct involvement from the consumer. Monetary incentives, grid constraints, and mobility needs of the consumer can be accommodated by the aggregator. It should be noted that the utilities can also be aggregators. The guaranteed demand response from consumers can be bid into the capacity or ancillary services markets. The utilities can also coordinate with the aggregators to provide grid services.

There is a possibility to adopt algorithms that can minimize the charging cost whilst considering the limitations of EV and grid. Under this strategy, the algorithms used could be convex multi-time step problems and feedback can be integrated into the decision-making process. In particular, as EV battery sizes are small individually to offer system-level benefits, aggregation of demand enables effective utilization of EV charging. It is easier to convert public charging and programs to obtain grid benefits. On the UK streets, light poles have been converted to charging outlets which can be enabled for off-peak use and grid benefits with the help of aggregation [19, 25, 27].

Aggregation need not be limited to EV chargers alone and distributed energy resources, such as storage can be integrated to provide grid benefits. Battery assisted fast-charging infrastructure can help avoid costly grid interconnection and demand charges. This is useful when planning the charging of high battery-powered electric vehicles such as electric buses and electric ferries. In Hawaii and Norway, for electric ferry charging, battery-assisted EV charging is employed. When EVs are not charging and when EVs are charging, storage enables more grid responsive charging.

g. Smart Fleet Charging

One of the most important applications of the smart charging strategy is the charging of fleets. Economic benefits for charging make fleet operators ideal candidates for charging and responsive grid price and regulation signals. Maximum demand and load balancing technology can help avoid additional capacity investments at fleet charging locations. Electric bus depots are ideal locations for electric bus charging. Intelligent charge management in a bus depot catering to the needs of 130 buses can reduce the total demand at the bus depot from 5 MW to 2 MW [19].

The same fleet charging strategy can be applied for taxi fleets. Electric taxi fleets are a popular option for decarbonizing urban areas and are already operational in many European cities. The city authorities of Amsterdam have taken care to roll off dedicated charging points for their EV fleet. The City of Rotterdam has gone one step ahead and ensured that electricity generated from renewable energy sources is supplied to their charging stations. Zurich has taken care to ensure fast charging facilities are available for their taxi fleet. In London, Uber carried out a trial with 50 electric vehicles. This was distinct as most EV drivers used on-street charge points for overnight charging as they lacked access to residential charging. Apart from this, the most popular charging option for recharging was rapid charging points. Finding a suitable point for rapid recharging is a continuous concern for partner drivers [22].

For fleet charging solutions, multiple objectives, including peak management control and renewable charging, can be integrated. This becomes an economic case for fleet operators as the cheap cost of renewable energy makes it a viable alternative. Fleet operators are natural aggregators because of the aggregated capacity of the batteries from the many EVs in their fleet and can earn additional revenue by providing grid benefits. This is a strategy that is expected to have significance in the future due to the synergies between shared autonomous electric vehicle fleets and fleet charging strategies [28].

h. Solar EV Charging

Using solar energy for EV charging is economical. The cost of electricity from Solar PV is getting cheaper as the price of solar panels falls. Apart from the 'green aspect,' there are other benefits from solar EV charging. The advantages of a Solar EV charger would also include a reduction in grid electricity demand on the grid and a reduction in grid impact of PV, as an EV battery is also energy storage. The ideal case of solar EV charging is when the DC power from Solar PV is fed into the EV batteries via a controller. A low voltage DC microgrid is an effective strategy to charge multiple EVs from a single solar source. Dynamic charging of EVs goes hand in hand with variable PV generation as an ideal match, as EV charging power varies with time [32].

Th ere are two common possibilities of Solar EV charging. The most popular one is through a PV-Grid charger, which is when grid power complements PV generation. The charging rate of EV can be maintained at any rate with inputs from both PV and the grid. With the proliferation of net metering technology, PV-grid charging solutions are being adopted by charging service providers as it helps them reduce demand charges. If the Solar PV generates more power than what is needed for EV charging, the excess power is fed to the grid. If PV generation is lower than the charging demands, the remaining charging power will be supplied by using grid electricity. If the solar system has tripped due to any fault, then grid electricity will cater to the charging alone. Where there is no charging of EV, solar generation will not go to waste if the grid acts as the battery. The other

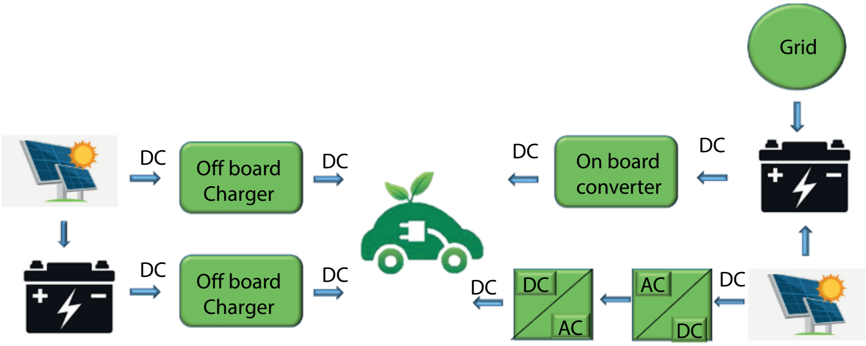

Figure 3.8 Multiple possibilities of solar EV charging.

solution is a PV standalone charger where the solar plant is oversized to meet the complete EV charging demand and such solutions are not possible without battery storage [33]. Multiple possibilities of solar EV charging is shown in Figure 3.8.

Though Solar EV charging is a strategy that can be implemented under other strategies, as it is an important case to ensure decarbonization of transport, it is discussed distinctly. The vehicle to grid communication strategies enable variation and shifting of charging load to high periods of renewable energy, as the higher share of renewable energy typically coincides with lower electricity prices and a higher need for flexibility in the grid. Hence, with one strategy, multiple economic and environmental benefits can be obtained [20].

In the UK, a smart meter based application can recognize the generation source and direct it to EV charging. The user can manually choose or automatically control the time of charging. It is possible to use self-generation at the consumer's premises to charge electric vehicles. There are many car parking spots fitted with rooftop solar generation and the solar generation at the site can be used for EV charging. It is important to have a control strategy that reduces the charging demand when the consumer is using more power than solar generation and vice versa [22].

i. Smart Battery Swapping

Battery swapping is a charging technology in which a vehicle's discharged battery is replaced by a charged battery in less than a few minutes. Battery swapping depends on predicting, managing, and extending battery life. The commercial viability of a battery swapping model depends very much on the health and life of a battery. There are factors that affect battery life, such as excessive charging and discharging, high and low temperatures, deep discharge, the rate at which the battery is charged, etc. Two-wheelers and three-wheelers are gaining traction in the battery swapping models in India. An EV user would expect ease of using the vehicle with features like getting a reminder well in advance about the remaining charge of the battery, time, and distance the EV can cover with the remaining state of the charge while receiving a notification about the nearest battery swapping station. Further, mechanisms where EV owners can book charged batteries in advance can be adopted as shown in Figure 3.9. Intelligent Internet of Things (IoT) provides the charge level of the battery and provides guidance on which battery to select at the battery swapping station. It is thus important to explore smart features in the battery swapping models using cloud services, analytics, and artificial intelligence to deliver better solutions to the users and service providers. Companies are already coming up with lucrative business models and technologies.

For example, sensibility has come up with a 'pay-as-you-go' model that allows EVs to be financially viable. It offers developing an open architecture that allows all forms of city transport, having a flexible and modular interchange station that can be strategically placed in a citywide network,

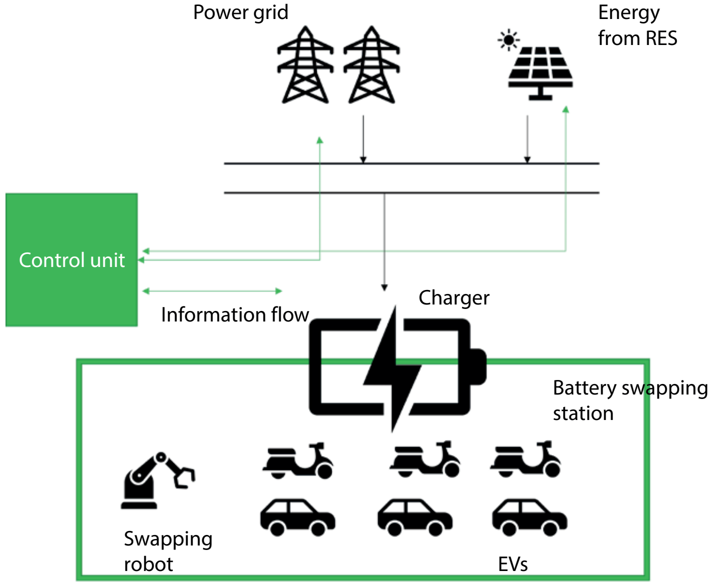

Figure 3.9 Schematic for smart battery swapping.

designing interoperable multi-platform batteries that are easily swappable between vehicles of various types and manufacturers and powered by renewable energy sources [10]. Battery swapping is a technology that was also piloted for electric cars. In Tokyo, in 2010, a trial for electric taxis was conducted on conventional cars converted into electric cars with replaceable batteries [22].

3.4 Evaluation of Charging Strategies

Smart charging implies the control of charging time or rate of EVs against the constraints of the grid, while matching the needs of vehicle users. With smart charging strategies, the charging demand can be used to reduce the demand during a peak period, shift charging demand to an off-peak period, and assist in load-generation balancing of the grids. The penetration of smart metering technology, with the support of cost-reflective pricing and demand-side management strategies, can help control the EV charging load. Multiple algorithms can be used to manage the charging demand and these strategies can provide financial benefits to both the customer and the utility. One of the most important needs for utilities now is flexibility for accommodating the high growth of variable renewable energy sources. When the EVs are parked, they can provide a range of grid benefit services to the power system, depending on the smart charging strategy [13, 21, 23].

Initially, most of the charging strategies were planned for controlling the maximum demand and optimizing the cost. However, with the evolution of the grid, the need for increasing flexibility in operation and evaluating the impact of EV charging loads on the distribution grid has also become important. The flexibility of EV charging demand will depend on the travel behavior of consumers. It will depend on the amount of charging load that can be time-shifted without interfering with the EV owners' travel patterns. This flexibility is handy in ensuring the maximum utilisation of renewable energy as well. This is an important consideration because the off-peak demand is supplied from fossil fuel sources. The need for flexibility increases while decarbonizing the grid and EVs can assist in grid support for integrating renewable energy sources. The flexibility benefits can also provide ancillary services for frequency response and spinning reserves. In Table 3.1, an evaluation of the disgust charging strategies against the four objectives is presented below [29-31].

Table 3.1 Evaluation of different charging strategies.

Strategy	Peak management	Green charging	Flexible resource	Optimal cost
Time of Use Rates	Yes			Yes
Load Control	Yes			Yes
Smart Pricing	Yes	Yes		Yes
First Come, First Serve	Yes			Yes
Coordinated Charging	Yes	Yes		Yes
Cooperative Charging	Yes	Yes	Yes	Yes
Smart Fleet Charging	Yes	Yes	Yes	Yes
Solar EV Charging		Yes		Yes
Smart Battery Swapping	Yes	Yes	Yes	Yes

It is logical that shifting EV demand from peak demand time can provide benefits to the grid by avoiding cost and capacity. The ability of an EV to contribute to both systems and local flexibility depends on the number of travel hours. As flexibility at the bulk system level is obtained from generation, a distribution system flexibility from distributed energy resources, such as electric vehicles, is largely untapped. With the increasing penetration of rooftop solar PV, the interaction with electric vehicles becomes an important consideration. Increasing dependence of charging on renewable electricity generated at the site and reducing the energy bill are two features that should be part of future charging strategies. Overall, any smart charging strategy for EVs can help integrate renewable energy and decarbonization of the grid.

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