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ELECTRIC VEHICLES AND INTERMITTENT ELECTRICITY PRODUCTION

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INTRODUCTION

A critical component in the ongoing development of electricity utility infrastructure is the increasing inclusion of environmentally-friendly and renewable sources of generation, as well as increasing the adoption of technology which can utilize this energy.[1] Modernization of the electrical grid is very likely to see a drastic increase in the amount of electrical energy being produced from renewable sources such as wind and solar. While the reduced environmental impact and low marginal production costs of renewable energy compose a set of readily apparent benefits which motivates the inclusion of renewable energy generation technologies in the modernization of the electrical grid, the use of these technologies is not without its own obstacles.

Owing to the nature of the renewable energy sources (primarily wind and solar), it is impossible to predict the energy production of such a source with complete

1 See Chapters 5, 6 and 8 for discussions on the importance of renewable energy sources for the efficiency and environmental impact of electromobility.

certainty. Even though probabilistic variations creating forecast inaccuracy lead to difficulties in operational planning of reserves, perhaps the greater challenge of renewable energy resources is their intermittent nature, i.e. there is no method available for controlling the timing or the rate of energy production coming from the original source. Incorporating small amounts of renewable generation requires little modification to the power system, but as the share of energy derived from renewable sources increases it will become important to supplement renewable generation with technologies for energy storage and flexible consumption which can make use of renewable electrical energy in an effective manner. Electrified vehicles have the potential to meet this supplemental need, given the flexibility in the charging of vehicles over time as well as their inherent ability to store electrical energy.

Not only is the nature of the physical components (the renewable and traditional generation sources, the electric vehicle charging loads, and the electricity network) important in analysing the contribution that electric vehicles can have on integration of renewables, but the method of control also plays a critical role.

A proper control strategy for electric vehicle charging needs to meet energy demands for transportation (Electric Vehicle Loads) while it minimizes need for network reinforcements (Network Constraints) and improves efficiency of the electricity generation system (Renewable Energy Sources).

RENEWABLE ENERGY SOURCES

Electricity generation systems have traditionally been supplied by fossil fuels, but are likely to rely increasingly on wind, sun and biomass in the future. However, as seen in Figure 9.1, the electricity generated by wind or solar power varies in time and is non-dispatchable, whereas thermal units are most efficient if run continuously at rated power.

In a thermal electricity generation system complemented with wind or solar power, variations in load and renewable generation can be managed with three different strategies: *part-load operation* of selected thermal unit(s), *start-up and shut down* of selected thermal unit(s), and *curtailment of renewable power*.[2]

Operating thermal units at part-load is associated with an increase in costs and emissions per unit of electricity generated, since the efficiency of a unit decreases with the load level. The start-up of a thermal unit may take hours to days, during which time the unit consumes fuel without generating electricity. Curtailment of renewable power implies unnecessary costs due to discarding the zero marginal cost energy, as well as excess emissions at some thermal unit in the system.

Inclusion of electric vehicle charging in the power system demand represents yet another source of potential load variations which the electricity generation system needs to manage. However, the inclusion of electric vehicles in the electricity generation system presents an opportunity for a fourth option for variation management: *regulated vehicle charging*. Utilizing an appropriate charging strategy,

2 Göransson, L. (2009). Wind power in thermal power systems. Licentiate Thesis. Chalmers University of Technology

electric vehicles have the potential to reduce the need for part-load operation and thermal cycling of thermal units, and decrease the likelihood of curtailment of renewable generation.

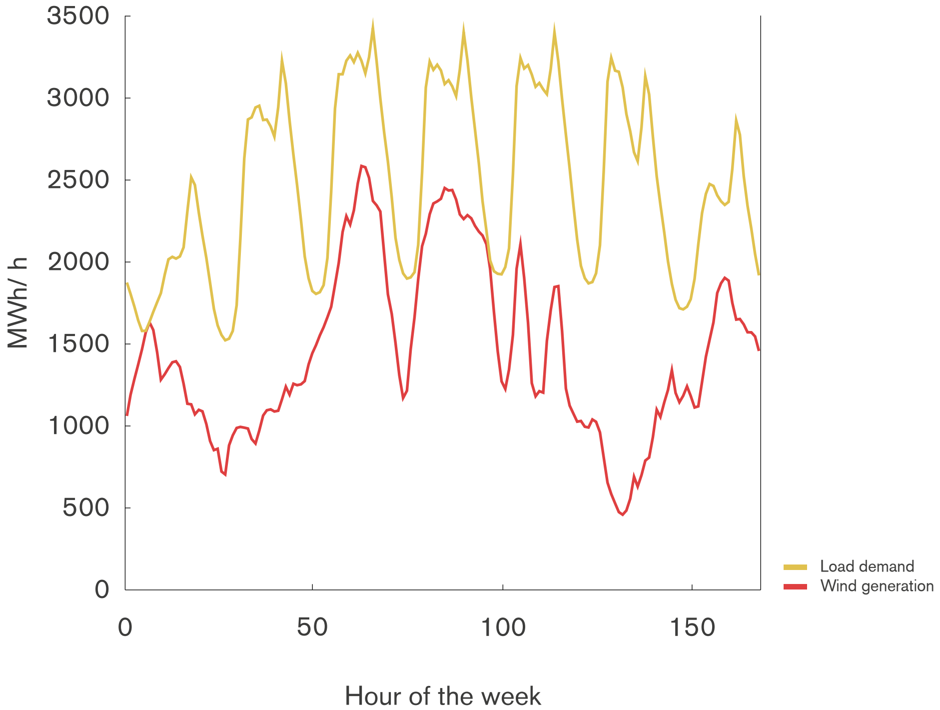


Figure 9.1 Weekly load demand and wind generation fluctuation sample data from Western Denmark. The intermittent variation of the wind output is seen to be uncorrelated to the daily load variations, which can thus reduce reliability and efficiency of the electricity system.

The potential of electric vehicle charging to manage variations in the electricity generation system depends on the charging strategy and the nature of the variations. Variations in demand for electricity follow a diurnal pattern with low demand for electricity at night-time. Electricity generation systems are designed to manage the diurnal variations in demand by letting some thermal units have better cycling properties, at the expense of higher running costs. These units are only operated during the day, when demand is highest. At night, only units with low running costs and poor cycling abilities are left in operation.

By utilizing electric vehicle charging as a method of managing variation, cost-effective integration of renewable generation is facilitated. During the daytime, quick cycling thermal units can adapt to renewable generation output at little expense in terms of efficiency in operation. At night, when demand is closer to base load generation output, an excess of renewable generation would be likely to require part-load operation of the base load thermal units, or curtailment of the renewable generation. Through night-time charging of electric vehicles, the competition between wind power and base load units can be avoided.[3] There are also seasonal variation in wind and solar power output, but variations spanning over time horizons longer than 24 hours are unlikely to be managed by vehicle charging, since it requires an overinvestment in battery capacity in the vehicles.

3 Göransson, L. et al. (2010). Integration of plug-in hybrid electric vehicles in a regional wind-thermal power system. Energy Policy, 38 (10) pp. 5482-5492.

ELECTRIC VEHICLE LOADS

In order to understand how electric vehicles may interact with intermittent electricity production through grid connection, an understanding of how electrified vehicles may be used must also be established. The availability of the energy storage resource in electric vehicles will have a probabilistic variance which will depend strongly on factors such as the quantity of electric vehicles in use, the geographic layout of a particular location, and the time of day. The typical user of a personal electric vehicle will tend to use the vehicle to commute from home to work in the morning, and return to home in the evening. Depending on the charging strategy used, the vehicle usage pattern, along with the physical location of residential and commercial areas within a city, may have a strong influence on the availability of storage resources throughout the day. Additionally, the desired charging pattern for the typical user involves charging the vehicle at home, which implies an increased availability of storage resources in residential areas during the evening and night time. Owing also to the investment costs and bureaucratic obstacles related to charging infrastructure, home recharging is likely to remain the predominant option, especially in the near future. For commercial electric vehicles, both the timing and location of charging is likely to follow a more predictable pattern.

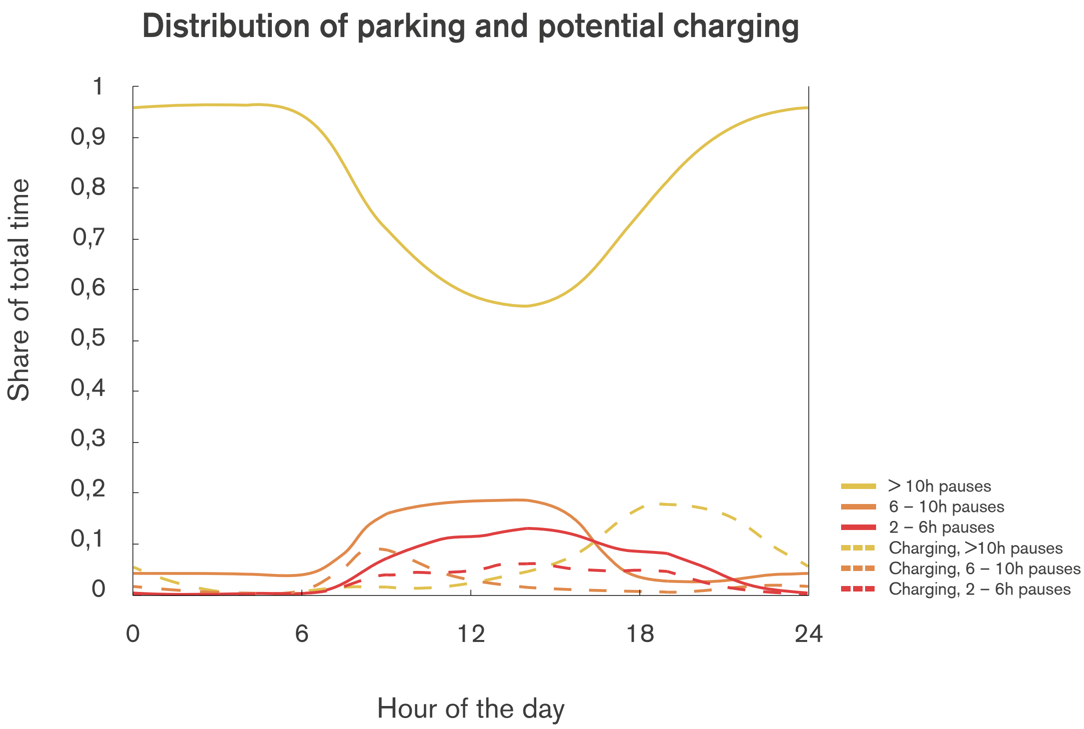


Figure 9.2 The distribution in time for parking of different lengths and potential charging during these pauses. Assumed: PHEVs with 2 kW charging immediately after parking which continue until battery is full (10 kWh) or pause ends. Energy use 0.2 kWh/km in Charge Depletion mode. (From Kullingsjö and Karlsson, 2012)[4]

To actively utilize the storage capacity of electric vehicles, there must be both the possibility and a willingness from the vehicle owner to accept an alteration of the time period over which the charging occurs. An estimate of the usage and charging patterns for electrified vehicles can be obtained by observing movement pattern data for the current conventional vehicle fleet. Figure 9.2 displays the

4 Kullingsjö, L-H, S Karlsson, 2012. The Swedish car movement data project. In Proceedings to EEVC 2012, Brussels, Belgium, November 19-22, 2012.

parking patterns for privately driven conventional vehicles in Sweden. The figure also displays potential charging loads derived from these driving patterns, assuming that the cars are PHEVs and are plugged in and charged immediately upon parking. The charging is assumed to have a consumption of 2 kW per vehicle, and lasts until either the battery is full or the parking is ceased.

From this data, it is seen that parking for periods exceeding 10 hours occurs primarily during the night, but may also occur during the day, due to the presence of vehicles which are not used daily and may remained parked for several days. These extended parking periods typically take place within residential areas. Without some method of control, the charging will be concentrated in the evening, when many commuters arrive home. There is a risk that this charging will coincide with the typical evening peak in residential electric load, if some control method is not applied to delay charging. Parking for periods of 6 to 10 hours is highly connected to commuter driving patterns, where the charging would occur in the morning when the driver arrives at work, mainly in commercial or industrial areas. There is additional charging risk because commuter vehicle charging at work coincides with commercial power demands. Shorter parking periods between 2 to 6 hours is distributed more evenly over the day, as would be the corresponding charging.

If the charging time of electric vehicles is not actively controlled, the charging load can do little to benefit the integration of renewables. However, customer willingness to provide a flexible charging demand alters from customer to customer, and may also vary based on customer circumstance. The greatest opportunities for flexibility exist when the next instance the vehicle will be needed for transportation are well known, such as residential charging when the vehicle is needed the following morning, or commercial charging when the vehicle is needed at the end of the work day. Future developments in battery technology may have a strong impact on the possibility of flexible charging, because expensive batteries will motivate a vehicle having a small battery which will need to be charged often. When cheaper battery technologies become available, it becomes more reasonable that flexible charging could occur overnight at home.

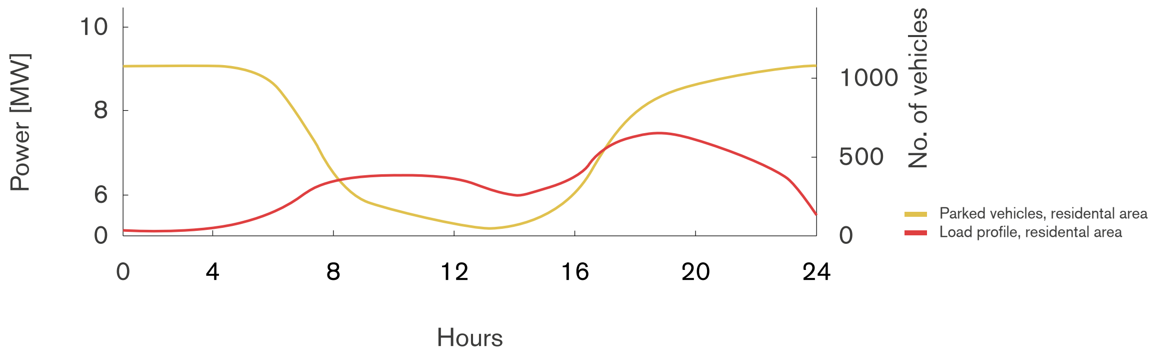
For a more detailed description of expected usage patterns of electric vehicles, please refer to Chapter 10. In this case, it is sufficient to mention the underlying pattern of electric vehicle usage, without explicitly defining the detailed properties of electric vehicle charging and storage availability.

NETWORK CONSTRAINTS

When analysing the impact of electric vehicles within the energy infrastructure, it is important to consider not only the way in which the vehicles will interact with generation sources, but also to consider what impacts electric vehicles will have on the electric grid. In some cases it may be necessary to select a charging strategy for the present EV penetration level in order to reduce stresses on the network. If this coincides with the need for a more intelligent charging strategy, the additional intelligence may be utilized simultaneously to facilitate further integration of renewables. Thus, even though a charging control strategy may be selected based on addressing network constraints, an increase in renewable penetration may be yielded from the control infrastructure.

Essentially, an increase in the penetration of electric vehicles within a network will be accompanied by an increase in the net electricity demand placed on that network. From a network perspective, the additional demand poses little problem, because the network is designed to handle peak load conditions, and the majority of the time operates below this limit. However, while providing the net energy demand of a fleet of electric vehicles is feasible, both the timing and location of the electric vehicle charging loads can have significant impact on network operation.

As shown in Figure 9.3, most vehicles are parked during the time when the electricity demand is high. If a vehicle owner starts charging the electric vehicle immediately after each journey the total power demand may exceed the peak capacity of components in the network.[5] Though it is highly dependent on the individual network, the increased load from electric vehicles has the potential to cause thermal stresses and under-voltage conditions, which has the potential to accelerate component aging or cause service interruption. It is clear that in these cases, it is not the energy demand of charging the vehicle which can lead to these complications, but it is the net power demand in the network due to the timing of the vehicle charging load. Thus the utilization of electric vehicle charging for energy storage must be managed in an intelligent way, through the use of appropriate market models and communications technology.



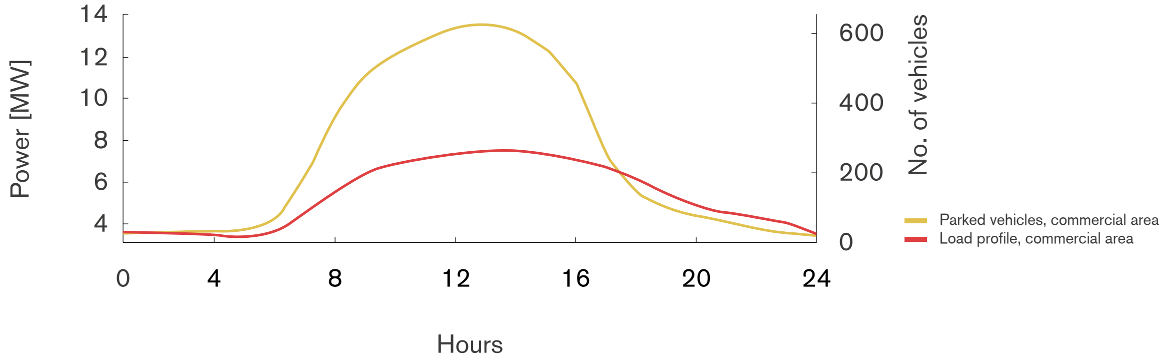


Figure 9.3 Parked vehicle and load profile comparison for a selected residential and commercial area. Note the correlation between peak loading and vehicle parking in these areas, indicating that uncontrolled charging strategies will increase peak loading constraints.

5 Steen, D. et al. (2012). Assessment of Electric Vehicle Charging Scenarios Based on Demographical Data. IEEE Transactions on Smart Grid, 3 (3), pp. 1457-1468.

In many cases, variable pricing is proposed as a signalling method for promoting electric vehicle charging during hours in which electric power is cheaper to produce which often coincides with periods where the network is uncongested. Locational pricing provides a convenient method of reflecting both the availability of supply and the effects of network congestion in a single price signal. However, while locational pricing may provide an effective method for promoting system-beneficial vehicle charging, it is important to understand the limitations of these price signals. Between any areas which have separate price signals, stress in the network can be properly reflected in the price. However, within a single price area, there is no way to reflect network stress in the price signal. In effect, the resolution of the price signals is identical to the resolution at which network stress can be included in the price signals. To achieve higher resolution, the network may be divided into several small price areas, which may be difficult to implement due to legislation and fairness considerations. While locational prices are an important step in enabling vehicle charging, further control mechanisms may be necessary to avoid distribution network stresses.

The geographic distribution of electric vehicles is also important to consider, as this has a significant effect on how the grid may be stressed. Using modern battery technology, the relatively short travel range of electric vehicles (relative to conventional vehicles) will by necessity limit the usage of electric vehicles to situations which involve short commute distances between recharging opportunities. This would seem to imply that electric vehicle penetration may grow significantly in urban areas, but without significant progress in battery technologies, utilization of electric vehicles in a rural setting is likely to remain low. This implies that while the high-voltage electricity transmission network is unlikely to experience appreciable strain from the inclusion of electric vehicle loads, there is a much greater potential for medium-voltage distribution network stresses, especially near urban centres.

The influence of the geographic distribution of electric vehicles on facilitating the integration of renewable generation will thus be affected significantly by the relative location of the intermittent generation to the flexible load. A large-scale renewable generation plant will be constructed at the site which provides the most favourable conditions for generation, which often implies the generation is located a significant distance from the load. In these cases, there is no choice but to connect the renewable generation to the transmission grid to deliver power to the load centres. As renewable penetration increases, if a significant portion of the renewable energy is derived from distantly-located sites, the only available alternatives for ensuring network security will be reinforcement of the grid or construction of dispatchable energy storage facilities. Unless a vehicle-to-grid infrastructure is in place, electric vehicles will not be capable of contributing to network security. However, the presence of a night-time electric vehicle charging load will improve the load factor of the network, improving the utilization of the network.

In the case of locally-placed distributed renewable generation, electric vehicles may be able to contribute much more to network security. The presence of renewable generation in a distribution grid can lead to voltage regulation issues[6] and

6 Masters, C.L. (2002). Voltage rise: the big issue when connecting embedded generation to long 11 kV overhead lines. Power Engineering Journal, 16 (1), pp.5-12.

the flexible charging load of a fleet of electric vehicles can be utilized to promote voltage stability. This implies that through the proper coordination of the electric vehicle charging load, the renewable energy which is produced can be consumed locally, promoting the security and efficient utilization of the distribution grid.

CHARGING STRATEGIES

As mentioned previously, while an increase in the number of electric vehicles has the potential of providing benefits to the network as a flexible load or even a source of energy storage which can complement intermittent renewable generation sources, this is not without its caveats. Unless the charging of the vehicles is handled appropriately, the potential benefits of the resource may never be realized, and in fact their presence may even lead to detrimental effects within the operation of the distribution network. In this section, a number of charging strategies relating to penetration of both EVs and renewables, as shown in Figure 9.4, will be discussed which each involve different technical and economic approaches for addressing the management of electric vehicles within a network.

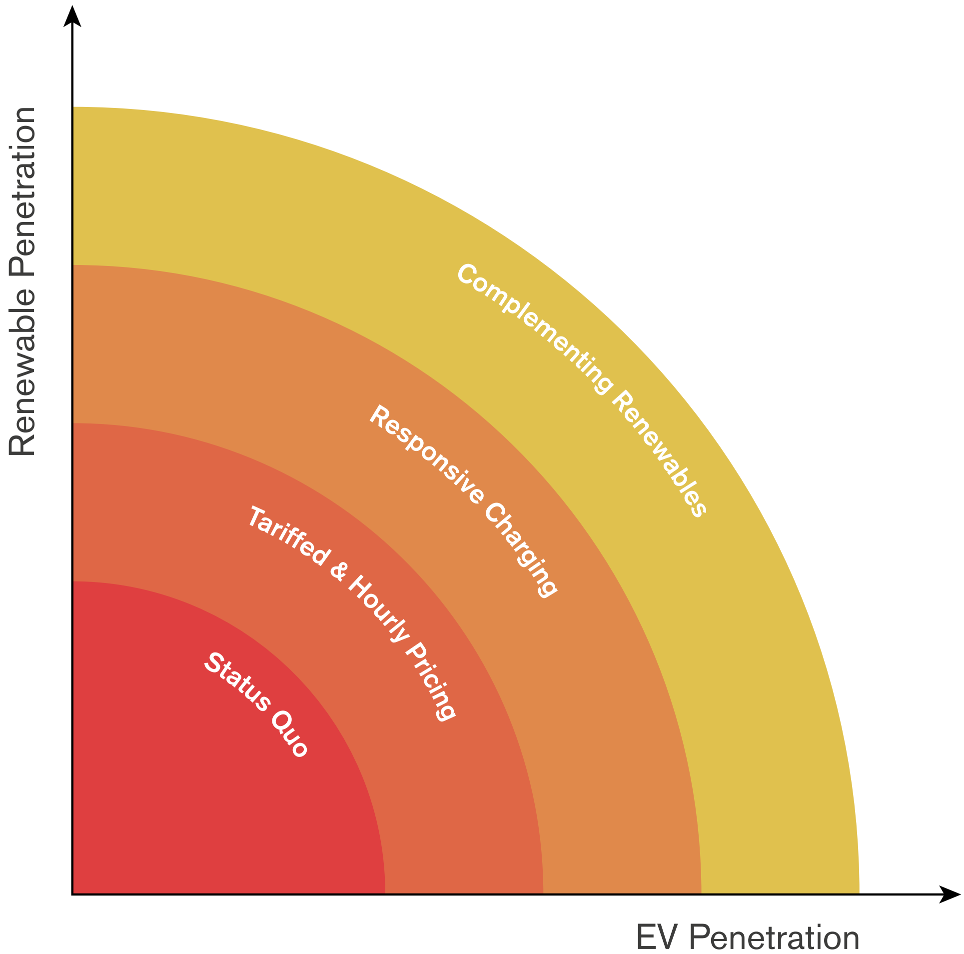


Figure 9.4 Guideline for the evolution of schemes for controlling electric vehicle charging to become a participant in the energy system. With increasing penetrations of either EVs or renewables, more advance controls are required.

STATUS QUO

The simplest option available for managing the charging of electric vehicles is to maintain the status quo of the current method of grid operation. This would require no alterations to the current market for consumer electricity, and would also require no capital investment in infrastructure changes. Essentially, the owner of electric vehicle would plug in the vehicle whenever they desired to charge the batteries, and the vehicle would simply appear as an additional load placed on the network when connected. The batteries would charge at a pre-determined rate until they reach their storage capacity, at which point charging would cease.

This option is the most readily available solution for systems incorporating electric vehicles, as it requires no alterations to the present market structure or electricity distribution systems. Because the vehicle charging is simply added to the inelastic demand or the electricity consumer, all that may be necessary is an analysis of the network to ensure there is sufficient capacity to handle the addition of these charging loads into the network. Note that due to the simplistic nature of such an approach, the grid is not able to extract any benefit from the presence of vehicle-based energy storage. It is also likely that the scheduling of generation to meet these evening peaks will lead to a decrease in efficiency and increase in cost of electricity generation.

This approach is likely the most suitable for addressing networks with low penetration of electric vehicles, and due to the moderate rate of increase in electric vehicle utilization, this is the preferred approach for near-term scenarios. When only a small percentage of the total energy demand of a network comes from electric vehicle charging, the vehicles will have negligible impact on the efficient and safe operation of the electricity network. However, as electric vehicles become a more popular and cost-effective technology, their usage will likely increase, motivating some alteration to the current operation infrastructure.

As electric vehicle utilization within a given area increases, the probability of the load demand exceeding network capacity increases correspondingly, and will eventually motivate an alteration in network operation to address these potential problems, as shown in Figure 9.5. The concern in these cases is that there is a chance that the instantaneous peak power demand in a network may exceed the network's capacity, and the risk of such an event is greatest when home charging of vehicles is performed immediately upon arrival at a residence, as the charging load will add to the early evening energy demands, for which there is already a significant peak.[7] Compounding on these issues are the stresses placed on the thermal generation units in the system, where accentuated evening peaks lead to greater strain and reduced efficiency of the thermal units supplying electricity. To alleviate the risk of such an over-capacity event, a charging strategy should be used which attempts to shift the charging demands to a more fortuitous time in the daily schedule, while still meeting the energy needs of the vehicle over this period.

7 Jardini, J.A. (2000). Daily load profiles for residential, commercial and industrial low voltage consumers. IEEE Transactions on Power Delivery, 15(1), pp.375-380.

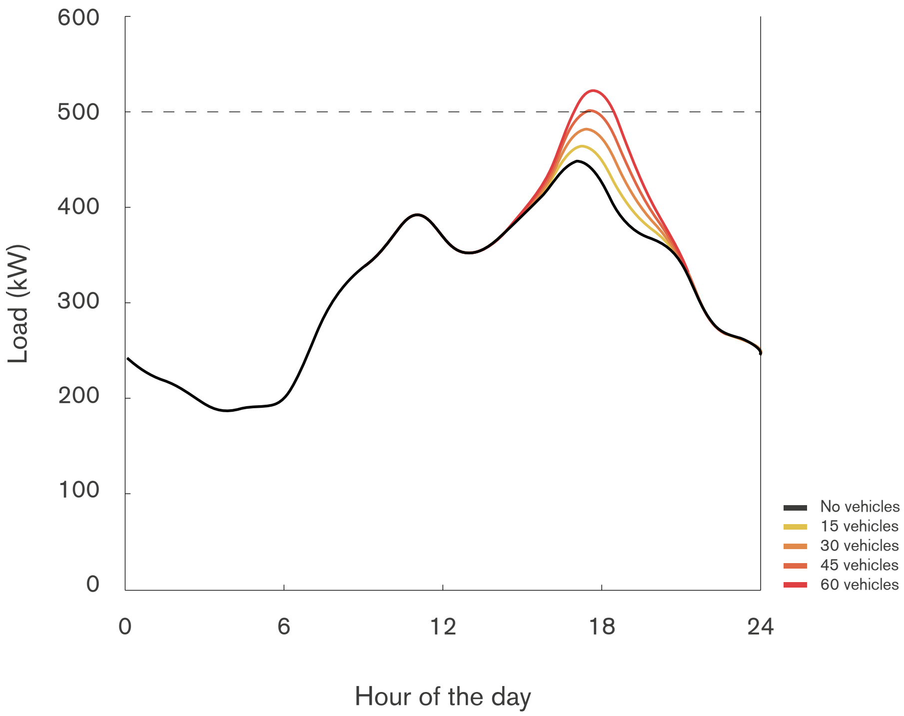


Figure 9.5 In the status quo case, the vehicles begin charging immediately upon arrival in the residential area. In this example, various numbers of EVs with 2 kW charging are connected in an area served by a 500 kVA transformer. It is seen this strategy can lead to overloading with significant EV penetrations. Note that the capacity for EV penetration will vary greatly from network to network.

TARIFFED & HOURLY PRICING

The challenges presented by the increased presence of electric vehicles in the system can be handled with relatively little change to the method of grid operation by modifying the energy pricing scheme, where variable pricing would be established in order to encourage the sale of energy to consumers during a time which is favourable for system operation. The desire of consumers to charge their vehicle at home, along with the typical daily energy use pattern, implies that a pricing structure may need to be established which encourages electric vehicle owners to charge overnight, during the late-night or early-morning time period. This would allow vehicle owners to meet their daily transportation energy requirements through home charging, as well as reducing the peak load on the grid by encouraging charging during lightly-loaded hours, as in Figure 9.6. Thus, establishing an energy pricing scheme which accurately reflects reduced overnight energy prices can simultaneously promote consumer energy cost savings, and a more secure and efficient system.

Another key benefit of establishing such a pricing structure to facilitate the integration of electric vehicles is the low cost of implementation for such a scheme. From a market perspective, very little needs to be changed, as the only difference is that customers will be charged a different rate for energy use based on the hour of consumption. The communications infrastructure required to implement variable pricing is relatively simple, where no communications to the customer are necessary for a fixed-price overnight tariff, and only once daily communications are required if the customers are charged the day-ahead spot market price. From a technological standpoint, in order to accomplish a variable price billing scheme, it will be necessary to collect hourly measurements of energy consumption from customers so that they can receive these price incentives. Smart meters which can collect and communicate this hourly data to the customers' energy supplier are the key technology for enabling this method of electric vehicle charging.

The variable pricing method will motivate customers to charge their vehicles during non-peak hours, and in the aggregate will shift demand to a more favourable time of the day for grid operation while yielding a monetary benefit to the customer. For moderate penetration of electric vehicles (whose level of penetration is grid-dependent) and for a system dominated by thermal generation where wind power supplies up to around 20% or solar power supplies up to around 30% of the load this scheme is expected to be effective. Night-time charging permits a more evenly distributed load on the thermal generation units. With wind power in the system, night-time charging of EVs will reduce competition between base load units (with poor cycling abilities) and wind power, resulting in reduced reduction of wind power curtailment and thermal cycling costs as a result. With less than 30% solar generation, solar power will not compete with base load during the day. Additionally, the charging demand will lead to better utilization of existing grid infrastructure while alleviating stress caused by evening demand peaks.

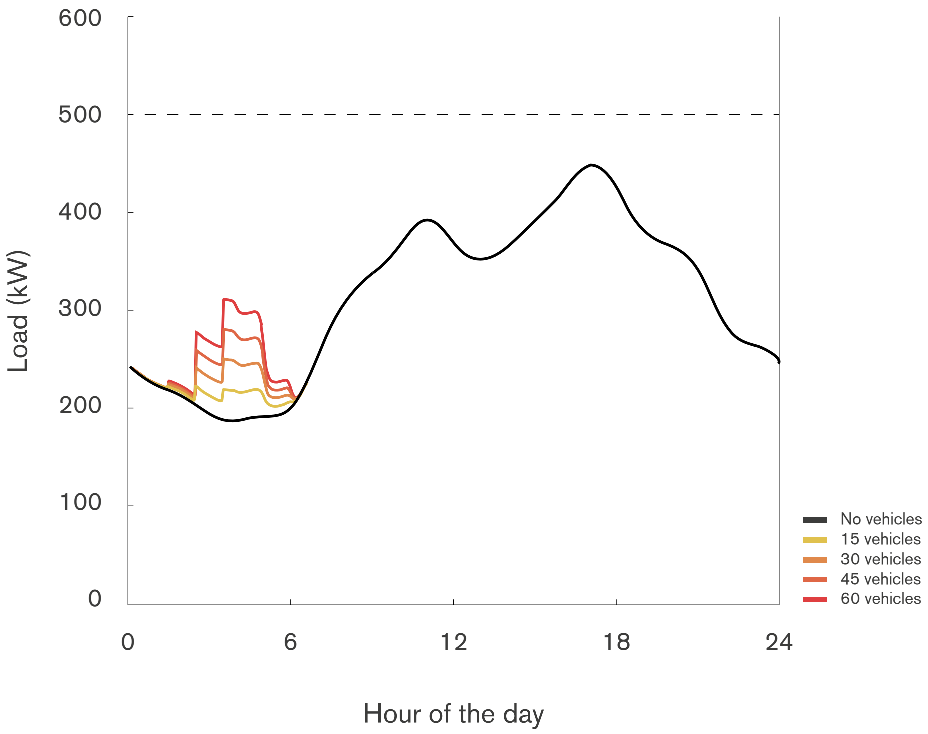


Figure 9.6 In the hourly pricing scheme, customers will charge their vehicle to meet its transportation energy needs by scheduling to charge during the cheapest available hours. Note that this may cause a localized night-time peak, as is shown for this distribution network. However, if there is system wide adoption of electric vehicles, the price advantage of the cheapest night-time hours will be diminished, and the peak displayed above will tend to flatten.

This approach, while effective for moderate quantities of electric vehicles and renewable generation in the system, is still limited in its efficacy for future scenarios with higher penetration of electric vehicles and renewable generation. Due to the relatively simplistic nature of the communications and market infrastructure, the demand of the vehicles is unresponsive to real-time renewable generation intermittency or system stress. Addressing this will require further advancement of infrastructure to permit more flexible customer demand response.

RESPONSIVE CHARGING

With increasing electric vehicle and wind penetrations of 20-40%, a more active charging control strategy must be employed to ensure reliable delivery of energy resources. Some further advancement of the control scheme is necessary to ensure that not only does the vehicle charging load get shifted to the low-demand hours of the night, but that there is also an effort to actively distribute the charging load over this time period in an effort to prevent night-time wind generation from interfering with base load generation, and to avoid network stresses. While there may be many available options for implementing this control scheme, two in particular will be presented here as alternatives for achieving this goal.

The first alternative involves a technological advancement of the fixed overnight price tariff. While the system would continue to utilize the fixed overnight tariff along with collecting hourly usage data, it would be upgraded to allow unidirectional communication signals to be sent to the consumer. The signal sent to the consumer would be used to indicate the time at which electric vehicle charging could begin. By being allowed to control the initiation of charging, a network operator could ensure that the number of vehicles charging at any given time would not exceed the capacity of the network, while also promoting charging at time which prevents renewable generation from negatively impacting base load generation. While the communications structure necessary to implement this system is relatively simple, the nature of customer interaction becomes more complex. Since the customer is giving up the right to independently initiate charging, some quality-of-service assurances must be provided to the customer to guarantee their daily transportation energy needs are met.

The second alternative also involves the implementation of unidirectional communication to the customer, but in this case the goal is to provide the customers with real-time energy price information so that they can independently choose the most favourable time to consume energy. In this implementation, rather than being offered energy priced by a predetermined set of tariffs, the price of energy for a given time period would be communicated to the customer and their energy consumption over this period would later be used to bill the customer appropriately. This method does not require the customer to forgo their right to select when their vehicle will charge, but it does assign to the customer the responsibility of selecting the optimal charging time. Since only the knowledge of past and present energy pricing information is known to the customer, it becomes the responsibility of the customer to attempt to forecast whether a more favourable price may become available, and then attempt to schedule vehicle charging according to this estimate. Forecasting in this manner will inevitably contain errors, which means the customer is forced to assume the price risk of charging their vehicle at a non-optimal time. Additionally, this requires significant attention from the electric vehicle owner, beyond what they may be willing to contribute.

Thus, a solution containing real-time pricing will almost certainly involve some sort of intelligent element in the vehicle which will seek to optimize the charging behavior. A device performing this function would likely employ some sort of statistical learning algorithm (such as a neural networks or support vector machines), using historical pricing information and current price trends to attempt to schedule the charging of the vehicle both optimally and autonomously. The need for an autonomous intelligent control agent leads to a system with more complexity and, due to the interactions that these control systems may have when operating simultaneously, could also lead to concerns about system reliability.

In either of the two cases mentioned, a modification to the current energy pricing structure and implementation of frequent unidirectional communications is required. The hourly energy usage data of a customer needs only to be measured, and the data can be collected once for each billing period. Figure 9.7 displays that by implementing these changes, a network will be capable of hosting a greater number of electric vehicles relative to the tariffed or hourly pricing cases, because unidirectional communications allows information to be sent to customers which subsequently enables an efficient control of load demand during the off-peak hours.

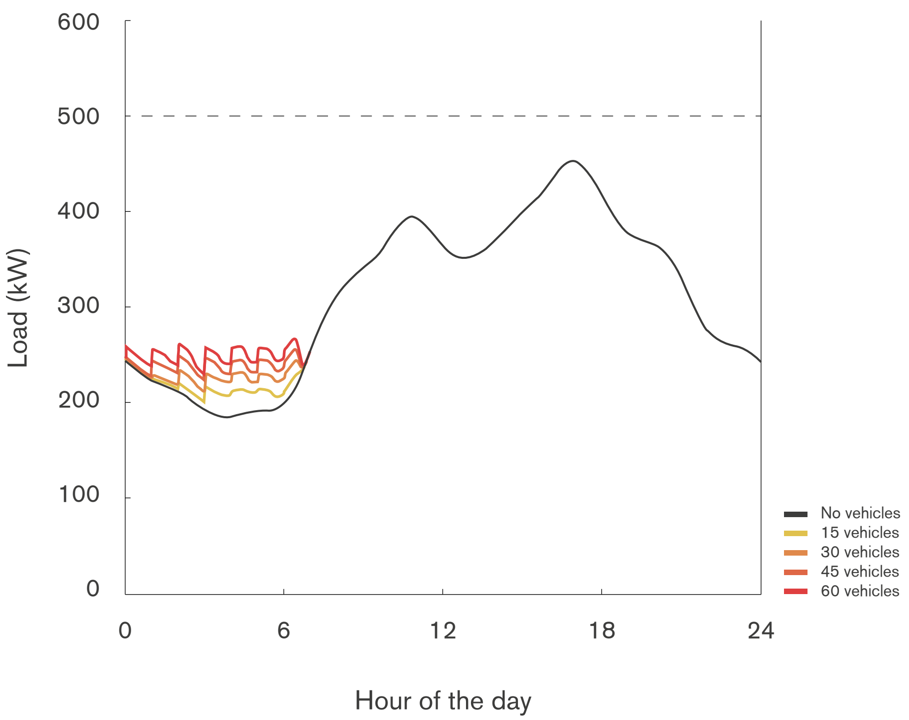


Figure 9.7 In the responsive charging case, an intelligent agent schedules the charging, whether it be some form of centralized or aggregator based control, or through real-time hourly pricing. The case shown here has the charging schedules optimized to minimize charging costs by selecting the appropriate hour in which to begin charging. Note that time resolutions finer than hourly scheduling are of course possible. While the effect here is displayed at the distribution level, note that a system wide increase in the night-time base load will be realized as a result of implementing such a control scheme at large scales.

COMPLEMENTING RENEWABLES

The goal of the charging strategies mentioned in the previous section was to develop the energy pricing and communications infrastructure used for the charging of electric vehicles, such that when customers leave their vehicles connected to charge overnight, not only will the charging be managed to ensure that the charging demand does not exceed the network capacity, charging will also be regulated to promote system efficiency. Those methods were promoted as a method of controlling the charging to facilitate the leveling of the off-peak load, utilizing the most economically produced energy when it is the most readily available. It would therefore be a straightforward extension of these charging strategies to control the charging of electric vehicles throughout the entire day to respond to the intermittency in a system with solar power corresponding to more than 30% of the demand or wind power corresponding to 40% or greater of the electricity demand.

This is essentially an extension of the off-peak charging control schemes to operate for all twenty-four hours of the day. This would imply possible billing complications, as the vehicle owners are likely to have used their vehicles to travel to a place of work or to a commercial centre during the daytime hours, which will require an enhancement of billing capabilities and an expansion of charging locations, if the customers are to participate in the real-time response of vehicles as energy storage.

In general, the use of electric vehicle energy storage as a controllable unidirectional demand seems to be the most practical implementation for the foreseeable future. These systems will require a much more modest investment in billing and communication infrastructure development when compared to electric vehicle charging schemes which also attempt to implement vehicle-to-grid energy flow. The unidirectional schemes are capable of achieving the goals of allowing electric vehicle storage to complement intermittent renewable generation, while facilitating favourable customer energy pricing and ensuring the stored energy in an electric vehicle will always be greater than or equal to the amount which remained upon its last use.

While unidirectional charging strategies are likely to dominate near-term scenarios, owing to its capabilities to address renewable intermittency with relatively little infrastructure investment, there may come a time in the future where the integration of renewable generation and electric vehicles in the electrical network is significant enough to warrant vehicle-to-grid energy flows. With increasing penetration of renewable sources comes the caveat of having increased variance in the amount of energy produced by these sources, owing to their non-dispatchability. There may be instances in networks with high renewable penetration where a shortage of generation motivates the use of the energy stored in the electric vehicles to support the network.[8]

Implementing a system which includes vehicle-to-grid will require significant investment, both in terms of alterations to the current market structure to allow

8 Saunders, C.S., et al. (2012). Congestion Management in Active Distribution Grids: Optimal Reserve Scheduling Under Distributed Generation Uncertainty. CIRED Workshop 2012, 1(1), pp.278-281.

electric vehicle owning customers to potentially sell generation capacity, as well as development of the bidirectional communications infrastructure[9] which would be required to support such a market. While vehicle-to-grid seems to be both infeasible and impractical for the current system, in future scenarios if there is substantial economic benefit to be yielded from avoidance of network investment or from retiring peak load generation units, it may warrant the implementation of such a system.

CONCLUSIONS

In this chapter, one of the key challenges of increasing quantities of renewable generation, namely that these sources are intermittent and non-dispatchable, is discussed along with the concept of how electric vehicles in a network can help address this intermittency. Electric vehicles inherently require some form of energy storage, which makes them a potential candidate to act as a complementary element to renewable generation. In electricity generation systems with a significant amount of thermal generation and a moderate EV penetration, a charging strategy implying night-time charging at low load hours is likely to be the cost optimal option. In systems with wind penetrations of 20%-40% and/or large EV penetration, the night-time charging should be actively scheduled to fit the forecast wind generation and EV energy needs in an optimal way. In systems with a large share of wind and/or solar power, solar and wind power generation may compete with base load generation or even exceed daytime demand which necessitates a 24-hour charging strategy.

However, there are certain complications which arise when attempting to use electric vehicles for energy storage, because unlike a fixed energy storage unit, an electric vehicle has a distinct daily usage pattern which dictates certain energy needs and a likely geographic relocation during daytime hours. Due to the diurnal pattern of usage, electric vehicles cannot address the weekly or seasonal variations of renewables. In an electricity generation system with a high renewables penetration, electric vehicles would thus be one of several variation management strategies.

9 Pahlavan, M, et al. (2011). Gulliver: a Test-bed for Ddeveloping, Demonstrating and Prototyping Vehicular Systems. Proceedings of the 9th ACM International Workshop on Mobility Management & Wireless Access, MOBIWAC 2011, pp. 1-8.