3. Developing EV charging infrastructure – International Experiences

3.1 Key considerations for setting up EV Charging Infrastructure

There are a range of requirements which distribution utilities and other stakeholders must consider while setting up a framework for supporting an EV charging ecosystem. These include having adequate guidelines and regulations in place, technical studies to assess and choose the right locations for setting up EV charging stations, ensuring channels for cost recovery of various network upgrades, enabling smart communication infrastructure for managed charging, setting up of TOU pricing mechanisms for off peak/dynamic EV charging, making charging services more accessible to consumers, and conducting training and workshops. These basic considerations are listed in the table below:

Table 9: Key considerations for developing an EV charging ecosystem

Parameter	Key considerations to be reviewed
Regulatory interventions	Inclusion of investments in EV charging infrastructure in the retail tariff
	Identify the tariff structure for EV charging (e.g., ToD tariff, special EV charging tariffs for EV users)
	Level of adoption of open access
Commercial interventions	Framework for public private partnerships / franchisee agreements for developing EV Charging stations
	Explore innovative business models such as pay per use
Techno – economic interventions	Adoption of smart grid capabilities, such as smart metering, "smart" charging (i.e., timed charging based on wholesale prices and other factors), vehicle to grid charging, assessing plans for conducting pilot programmes
	Managed / coordinated charging to mitigate distribution network impacts and facilitate RE integration (such as through load shifting to absorb excess RE generation): Provision for remotely controlling the charging speeds / duration of charging and modulating the same to enable optimal load on distribution system. Utilities can use managed charging to optimize the utilization of existing infrastructure and maintain grid reliability
	Explore how to lower the carbon and pollution footprint of EV charging (such as through solar coupled with storage)
	Charging stations need an adequate communication facility so that they can provide live information regarding their status, demand, energy charging pattern etc. Smart communication is key to the enablement of managed charging.
	Requirement for upgradation of network components such as transformers and substations for power supply, placement of static compensators, OLTC and other devices for voltage / frequency control
	Charging locations must be selected based on parameters such as availability of space, impact on traffic, commute patterns, business locations, and range of EVs etc.
Other elements of an enabling framework	Regulatory framework including legal aspects, licensing requirements, tariff etc.
	Specifying connectivity standards
	Specification of equipment standards
	Scientific planning and simulation models for EVSE siting

3.2 Key issues for setting up EV Charging Infrastructure

A detailed summary of the key issues with EVSE integration in distribution network is tabulated below:

Table 10: Key issues with EVSE integration in distribution network

S No	Parameter	Issue	Impact on network
1	**Voltage Stability and Harmonics**	• Non-linear load of EVs, sudden onset of charging load etc. may cause voltage unbalance, harmonics, voltage dips and may lead to voltage crossing acceptable limits at various nodes.	• Reduced Reliability • Voltage profile degradation makes system unstable • Affects equipment life
2	**Choosing appropriate locations for placement of EVSE**	• Identification of nodes that have a capability to handle external load is a key challenge. • Utilities shall be required to identify strong buses in the system for connecting EVSE, in order to maintain system stability. • Optimizing siting of charging stations such that congestion related to EV charging demand does not occur and the station is optimally utilized	• Hampers smooth operation of system if location is not optimal. • Voltage instability • Increase in Power loss if EVSE connected at weak electrical nodes • Congestion increase • Low utilization in case of sub-optimal traffic flow
3	**Tendency for uncontrolled charging in peak hours to result in** • **Requirement of Infrastructure Upgrade of T&D network** • **Procuring Costly generation sources for meeting peak demand**	• Uncontrolled charging would lead to increase in peak load demand, transformer overloading, line losses, and power losses shall become more relevant as EV penetration increases. • Due to overloading, transformer life may get impacted • EV charging at times of peak load would necessitate costlier sources of generation sources to be dispatched increasing the system costs	• Degradation of network components. • Increases network losses • Degradation in life of components Increase in Cost of operation
4	**Lack of clarity on potential impact of EVs**	• EVs in India have not seen heavy penetration and hence there is a lack of experience on the potential impacts of this load on distribution networks	• Technological unawareness

S No	Parameter	Issue	Impact on network
5	**Regulatory uncertainty**	• Uncertainty around regulatory approval of utility-owned charging infrastructure in the asset base. • No scientific method to determine actual cost-of-supply and associated tariffs	• Lack of transparent pricing scheme • Unforeseeable returns to investors
6	**Cost Recovery**	• Utilities will need to undertake investments for network upgrades required to facilitate EVSE integration.	• Lack of adequate cost recovery mechanism for investments shall put additional financial burden on utilities and may also impact the growth of EV

3.2.1 Voltage stability issues

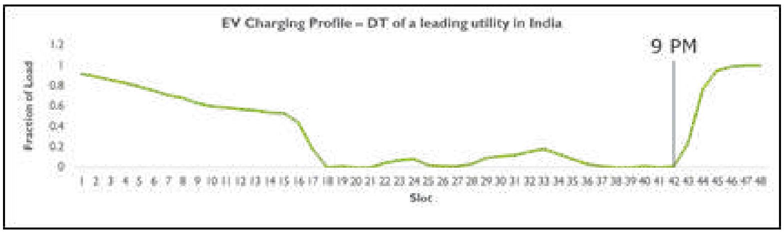
In the distribution network, due to typically high Resistance to Inductance (R/X) ratio of the distribution lines as well as non-linear load of EV, there may occur situations wherein heavy drawl of the power might lead to a significant dip in the voltage, which may cross acceptable technical limits. As EVs represent a large load in comparison to other household loads, they will increase overall power demand in low-voltage grids.

In addition to this, EVs may contribute to coincident load since drivers are likely to plug in their cars at the same time, during evening or morning system peaks, or when low tariffs start to apply. As shown in the graph below which represents a typical EV charging profile for a Delhi based distribution utility in India, the charging of EVs at the DT spike after 9 pm and peaks during the midnight which would generally represent that users charge their vehicles after returning home at the end of a work day. This time also represents the same window in which other domestic loads (such as lights, fans, ACs) will increase. The result is a higher coincidence factor on power demand.

Higher peak loads cause (relatively short-time) congestion on distribution grids, adversely impacting the voltage and network capacity. Overloads of network equipment can reduce the life expectancy of domestic components. These can also lead to voltage fluctuations outside their designated margins causing consumers' devices to malfunction at times of severity.

The following section illustrates the detailed impact on voltage and network reliability due to charging processes:

Figure 8: Sample EV Load Profile



- Reactive current: An EV stores energy in a DC battery, hence energy needs to be converted from the AC of the grid to the

DC for the battery. A general rule for convertors is that the cos phi value is not lower than 0.95 in order to avoid inefficient reactive power flows. The lower the cos phi value, the higher the amount of reactive current. Reactive current has to be transported via the grid which causes (heat) losses and reduces equipment lifespan.

- Harmonic currents: Converting the energy from AC (energy in the network) to DC (energy in the battery) can cause harmonic currents. This type of distortion results in multiple sinusoidal waves of frequencies higher than 50 Hz being distributed upon the 50 Hz sinusoidal wave of the current, as shown alongside. The higher the frequency of these harmonics, the more energy intensive they are and the more heat they generate in components.
- Voltage dips: Depending on the level of impedance in the grid (the lower the better) a high current can bring the voltage down. In case multiple EVs charge on a specific single phase of the grid (most of the current existing EVs have usually only single-phase design), it may lead to phase imbalance.
- Harmonic distortion of the voltage: When the current harmonics are high enough, and/or the grid impedance is high enough, the harmonics in the current can have a noticeable effect on grid voltage.

Standards such as J2894 issued by the Society for Automobile Engineers (SAE) can be followed to meet power quality standards requirement. SAE J-2894 Part 1 specifies the Power Quality Requirements for Plug-In Vehicle Chargers. This recommended practice includes guidelines for:

- Total Power Factor Power Conversion Efficiency
- Total Harmonic Current Distortion
- Current Distortion at Each Harmonic Frequency
- Plug in Electric Vehicle Charger Restart After Loss of AC Power Supply
- Charger / Electric Vehicle Supply Equipment AC Input Voltage Range
- Charger / Electric Vehicle Supply Equipment AC Input Voltage Swell
- Charger / Electric Vehicle Supply Equipment AC Input Voltage Surge (Impulse)
- Charger / Electric Vehicle Supply Equipment AC Input Voltage Sag
- Charger / Electric Vehicle Supply Equipment AC Input Frequency Variations In-Rush Current
- Momentary Outage Ride-Through

SAE J2894/1 defines the power conversion efficiency as a measure of how efficiently the charging equipment processes power from its input terminals to its output terminals. It can be measured over the total charging cycle or at any point in the charging cycle. It is a function of the design of the charger and, therefore, it can be a representative parameter for the charger. It has been calculated as the ratio between the instantaneous DC power delivered to the vehicle and the instantaneous AC power supplied from the grid in order to test the performance of the charger. The inverse of the efficiency of the charging process, i.e., a kind of energy return ratio

(ERR), has been calculated as the ratio between the AC energy supplied by the grid to the electric vehicle supply equipment (EVSE) and the energy delivered to the vehicle's battery.

SAE J-2894 Part II specifies the testing methods for Plug-In Vehicle Chargers. It includes guidelines for testing procedures for PEV chargers. Following are some standardized test conditions prescribed by the guidelines:

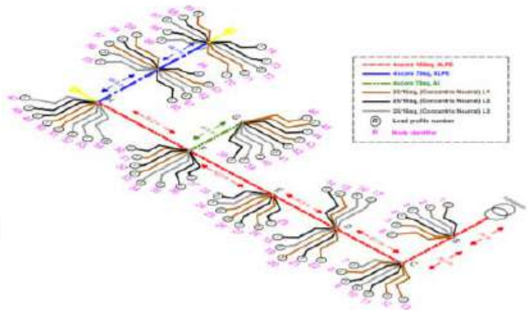
- Test room: - Room must be kept at 25 degrees C with a tolerance of 5 degrees C
- Battery: Must be within 17-33 degrees C at test start.

Case study[6]- Statcom placement of Irish distribution system with high EV charging level

A modelling study was conducted by Dublin Institute of Technology (DIT) on a representative Irish (urban) distribution network with substantial EV load. The impact analysis was done to model the high EV charging rate on single phase connected distribution network and STATCOM ability to mitigate the voltage magnitude and voltage unbalance issue. Key assumptions are highlighted below:

- The sample distribution system analyzed is shown in the diagram below.
- EVs are removed from the consumer grid connection between 9:00 am to 5:00 pm during office hours and charged outside these hours

Figure 9: Distribution System analysis for EV Loading



Source: Zaidi et. al., 2019, "Role of reactive power (STATCOM) in the planning of distribution network with higher EV charging level", IET Generation Transmission & Distribution.

- Representative travelling requirements of passenger cars are considered in order to design more realistic EV battery load profiles
- A normal battery size is considered to be 20 kWh, but recent advancement in EV battery capacity suggests a 40 kWh battery is available in the market and Electrical Buses battery capacities are in the order of 200-300 kWh

Table 11: Overview of the model

Details	Particulars
Platform	DIgSILENT power factory
No of customers	74, and connected from a 10/0.4 kV transformer in a radial network topology
Voltage deviation limits	+-10% of nominal value
Residential load modelling	Household load demand profile obtained from DSO
STATCOM placement	Connected at several pillars / locations to measure voltage profile without and with STATCOM placement

[6] https://www.researchgate.net/publication/330498865_Role_of_reactive_power_STATCOM_in_the_planning_of_distribution_network_with_higher_EV_charging_level

Details	Particulars
EV charging load	• Typical EV charging load pattern has been considered • 7 EVs are fully charged, and the remaining (90%) of EVs retain a state of charge in the range of 0%-90%. • EVs are randomly distributed on different phases on the network • Charging rates of 3.68 kW and 11 kW (single phase) are considered
Supply	Single phase 230V (line to phase voltage) via a distribution transformer with power rating of 0.4 MVA

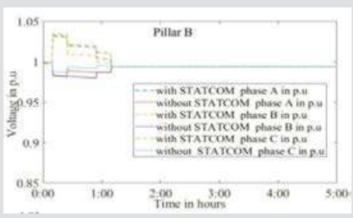
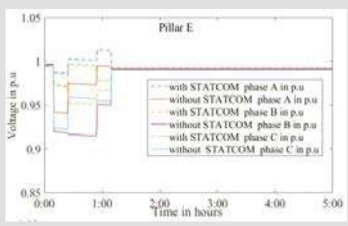
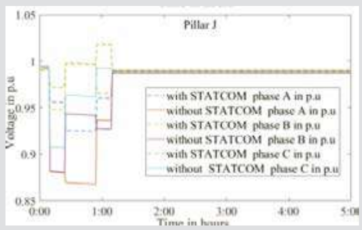
Source: Zaidi et. al., 2019, "Role of reactive power (STATCOM) in the planning of distribution network with higher EV charging level", IET Generation Transmission & Distribution.

Overview of the STATCOM deployed

- Can inject three phase sinusoidal balancing current into the grid in case of voltage deviations
- Can compensate for reactive power requirements of the grid in order to maintain voltage profiles adequately
- The compensator uses reactive power to control the voltage at given terminals
- The reactive shunt currents that can be injected by the STATCOM are based on voltage droop characteristics i.e. the slope of the droop characteristics determines the voltage regulation requirement of the system which the STATCOM would respond to
- The variation of power delivery or absorption is determined as per prevailing grid conditions

Key outputs of statcom modelling – Charging activity carried out at 11 kW

Table 12: Voltage Profile Using Statcom Modelling

Voltage profile at Pillar B - close to Supply transformer	Voltage profile at Pillar E – at centre of network	Voltage profile at Pillar J – farthest from Supply transformer
		

Source: Zaidi et. al., 2019, "Role of reactive power (STATCOM) in the planning of distribution network with higher EV charging level", IET Generation Transmission & Distribution.

The study insights are as follows:

1. The results suggest that EV penetration closest to the upstream medium-voltage (MV) grid will have less impact on voltage profile than EVs connected to the far end of the radial network
2. Under the analyzed consumer demand conditions, voltage breaches were not substantial

3. D-STATCOM, however, is able to reduce voltage drop quite effectively and as such also serves to reduce voltage fluctuations in the network.
4. The cost of such a device was ascertained to be $28000 (approximately £22000)
5. The analysis inferred that a D-STATCOM may increase the overall cost of augmentation and may not be the most cost-effective solution, but as a leverage for enhanced controllability and response time, it could be one of the optimal approaches.

Case Study: Using Storage and charging combinations for voltage stability

The high concentrations of simultaneously charging EVs could put strain on the distribution grid and cause frequency fluctuations, especially at high charging power rates. Another possible solution is to pair EV charging stations with stationary energy storage, which would allow utilities to flatten the electrical load and potentially increase renewable energy usage. Moreover, providing a decentralized/localized energy source for EV charging would reduce the congestion in the upstream LT network and arrest any voltage/frequency dips due to overload/overcharging.

Few case studies[7] of the same are mentioned below:

- Hawaii Electric Company has partnered with Greenlots to build DC fast charging stations with large battery storage to avoid upgrades in the distribution system and make use of Hawaii's substantial solar resources.
- In the United Kingdom, battery second life concept through the EVEREST system, which uses a large bank of used batteries to charge EVs and return energy to the grid to provide balancing services.
- The smart charging stations in the U.S. state of Tennessee, built by the Tennessee Valley Authority, include an on-site solar panel with batteries that supply 65% of EV charging power to minimize grid impacts and feed energy back to the grid when available
- The Energy OASIS project, developed by the British Columbia Institute of Technology, Natural Resources Canada, and BC Hydro in Burnaby, British Columbia, combines a large solar array, battery storage, and fast charging stations in order to allow fast charging with no impact to the electric grid.
- ElaadNL, working with Renault and the city of Utrecht in the Netherlands, is building 1,000 public solar-powered smart charging stations with battery storage around the Utrecht region
- BMW had, in 2016, partnered with Swedish power company Vattenfall to build a 2 MWh battery second life system designed to compensate for renewable energy fluctuations in Germany.

3.2.2 Power quality issues due to EV charging

The European Distribution System Operators in their publication titled "Smart

[7] *https://theicct.org/sites/default/files/publications/Power-utility-best-practices-EVs_white-paper_14022017_vF.pdf*

charging: integrating a large widespread of electric cars in electricity distribution grids" have noted that:

1. The additional energy consumption from EVs (kWh) will not represent a critical factor for DSOs, as this can be handled with existing generation capacity. However, EVs can cause a significant higher peak demand, which may trigger network upgrades unless load management strategies are employed.
2. EVs across Europe do not pose significant problems in distribution grids. As their share will be rising in the coming years however, DSOs will need to improve their network operations to meet a higher instantaneous peak demand.
3. The impact on the peak load will be critically dependent on how congestion is managed: if all EVs start to charge at the same hour, the impact will be much higher

Power quality issues could be preliminarily addressed through the following:

- **Automated and controllable tap changers on DT:** The taps in the transformer alter the power transformer turns ratio in a number of predefined steps and in that way changes the secondary side voltage.
- **Capacitor banks:** Capacitors are energy storage devices. They store energy as a static charge on parallel plates. They also improve the power factor.
- **Static Compensators** (STATCOM) in case the voltage dips beyond certain threshold, which adds up to the cost of the augmentation.
- Combining **decentralized battery storage systems** coupled with charging infrastructure to act as a local source of power

These voltage fluctuations become a major threat to the load served by the DT as domestic appliances connected in the downstream network are designed to operate under prescribed voltage limits and heavy and rapid fluctuations could lead to malfunctioning and permanent damage to these appliances.

As per a study by European Distribution System Operators (EDSO), it was found that On Load Tap Changer (OLTC) transformers are able to accommodate 100% of EVs in the network at normal/slow charging rates only, however the upgrade cost of each transformer is £60,000.

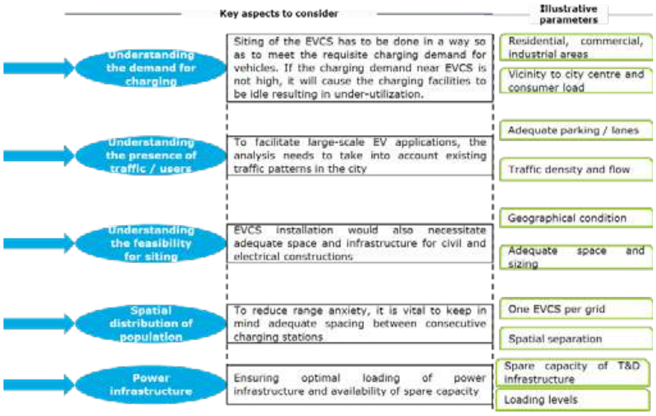
While tap changers on DTs and capacitor banks contribute to improvements in voltage profile, large scale installations of capacitor banks can cause resonance due to harmonics and switching transients. The main drawback of OLTCs are its high installation and maintenance costs. We focus on statcoms and battery-based storage systems in the following sections.

3.3 Location analysis and siting/design for EV charging infrastructure

This section discusses various factors associated with locating and designing EV charging infrastructure (EVCS). Factors such as the charging capacity required, preference of users for mode of charging (slow/fast), and the total EV load will depend on various geographical, technical and transportation parameters. Appropriate site selection and capacity determination of EVCS is a critical step to building a successful E mobility ecosystem.

A location close to the central point of a city will involve both heavy and slow traffic, and have commercial establishments; whereas locations in city outskirts will have fast moving traffic and a smaller population density. A location specific analysis is essential to identifying the needed charging capacity for a particular location. Also, prioritization of EVSE locations would depend on spare capacity in the Distribution Transformers (DTs) in the feeders connecting the EVSE stations.

Figure 10: Key parameters for siting of EV charging stations



Highlighted below are few case studies of cities where detailed locational analysis has been carried out.

Case study[8]- Siting and Design Guidelines for Electric Vehicle Supply Equipment

New York State Energy Research and Development Authority and the State of New York have published siting and design guidelines for Electric Vehicle Supply Equipment (EVSE). In these guidelines, siting and installation of EVSE depends on a number of considerations: proximity to power supply, parking space size and orientation, pedestrian traffic, lighting and visibility. Many of these considerations are not yet standardized in terms of functionality, and others fall outside the realm of the standards and codes system, such as aesthetics. Each EVSE installation will be different, so these guidelines take the important step of establishing baseline considerations that are predicated on a typology of sites.

The report suggests the following list of factors for site selection and site design:

Table 13: Location selection criteria: US Department of Energy, NYSERDA

Interfaces	Criteria for location siting / design
Network interface	• Presence of cellular network for car to parking spot communication • Consumer to charging network communication enables payment for publicly-accessible EVSE • EVSE to utility communication for enabling controlled charging • EVSE to grid connectivity for metering solutions
Urban interface	• Proximity to Traffic: Large-scale traffic patterns and counts determine viability of locations for most commercial operations, and such analytics may be used for EVSE location choice • Proximity to building entrances: Placement of the EVSE determines its visibility and accessibility, typically with respect to priority parking spaces—those that are located a short distance from building entrances. • Pedestrian traffic: EVSE and cord sets should not interfere with pedestrian routes; charging stations should not be placed in a location that would cause a cord to be a tripping hazard:

[8] *https://www.nyserda.ny.gov/Researchers-and-Policymakers/Electric-Vehicles/Resources/Best-Practice-Guides-for-Charging-Stations*

Interfaces	Criteria for location siting / design
Power interface	• Electrical capacity: Connecting EVSE to a power source will require evaluation of existing electrical capacity. This has two parts: the electrical system at the location of the EVSE installation, and the capacity of neighborhood systems to support many EVs charging at once. Electrical cabinets, panels and circuitry will need to accommodate the anticipated additional load. • Some municipalities, such as Vancouver, Canada, have used their building codes to require that new construction allow sufficient space within electrical rooms for panels and other equipment required to increase capacity in the future • Construction cost: The cost differential for EVSE installation is represented by the power interface. Considering a site's power sources and capacity will help plan for lower-cost installations that require less physical construction. • Proximity to power source: Installing the EVSE close to the required power source reduces the need for cutting, trenching and drilling to add new conduits to reach the EVSE. Additionally, the cost of installation can be reduced if the existing conduit has adequate capacity for EVSE.
Parking interface	• Parking Space Size: Availability of adequate parking space and minimal interference with adjacent traffic • Lighting: Visibility is critical for EV driver safety and helps to deter vandalism of the equipment. Most parking facilities are designed with lighting that is suitable for EVSE installations. Dim lights or cables can create tripping hazards • Accessibility: y to create spaces and routes that are safe and accessible to drivers of all physical abilities

Case study- San Pedro District of Los Angeles[9]

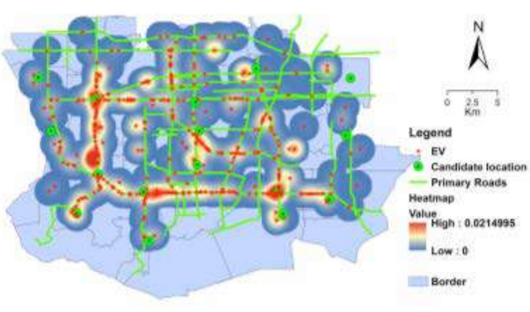
A general-purpose simulation software—The EV Virtual City 1.0 using Repast was used. The Repast based tool is a Complex adaptive system composed of interacting and autonomous variables which influence each other. With this kind of modelling, the full effects of diversity of a dependent variable can be brought forward and how they lead to overall dynamic behavior of a given system can be determined.

The simulation software is designed to construct a virtual digital city by integrating a variety of data and information, such as geographic information, demographic information, spatial infrastructure data, urban road network graph, electric power network graph, travel pattern, diurnal variation in traffic flow, seasonal fluctuation of driving activities, social interaction, etc.

Traffic related data: Data of San Pedro District of Los Angeles was used. The road network data from the U.S. Census Bureau is uploaded into the simulation software. In addition, the centroids of locations of residence, restaurants, supermarkets, shopping centers and workplaces using Google Maps is determined.

Figure 11: Snapshot of Traffic Data of Sand Pedro District

Snapshot of traffic data



Source: Lou et. al, 2015, "Placement of EV Charging Stations – Balancing Benefits Among Multiple Entities". IEEE

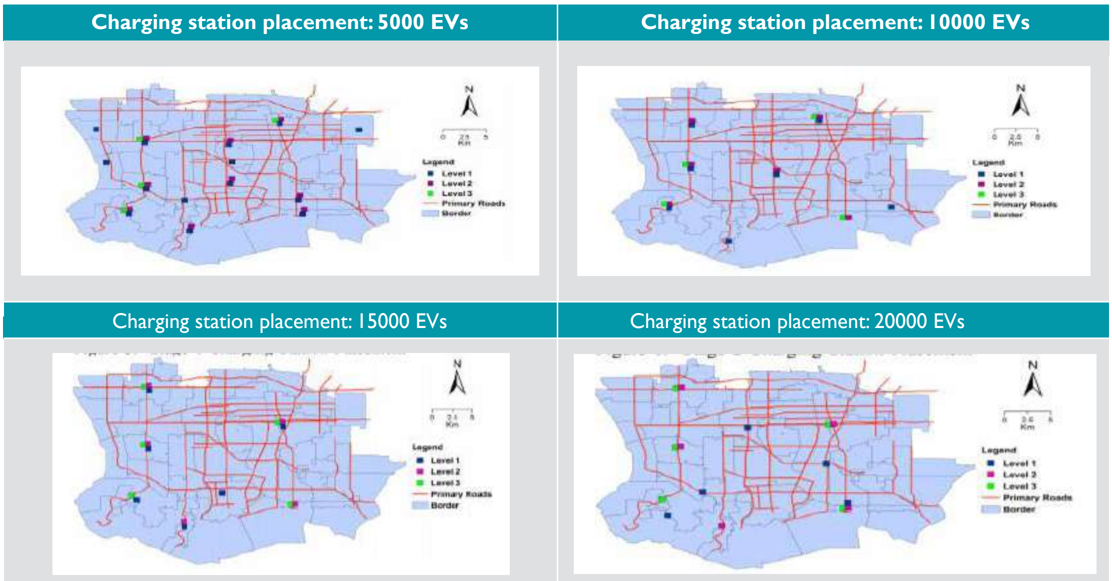
[9] *https://arxiv.org/pdf/1801.02129.pdf*

Distribution network data: From the California Energy Commission website, maps of transmission line and substations of San Pedro District were obtained and used in the simulation. This area has 107 substations in total. For each charging station placement option, the simulation used MATPOWER to calculate power flows, losses, and loading levels with and without EV charging.

The simulations were done for different EV penetration scenarios viz. 5000 EVs, 10000 EVs, 15000 EVs, and 20000 EVs.

Results of the simulation are summarized in following tables:

Figure 12: Illustration of charging station placement with varying EV penetration



Source: Lou et. al, 2015, "Placement of EV Charging Stations – Balancing Benefits Among Multiple Entities". IEEE

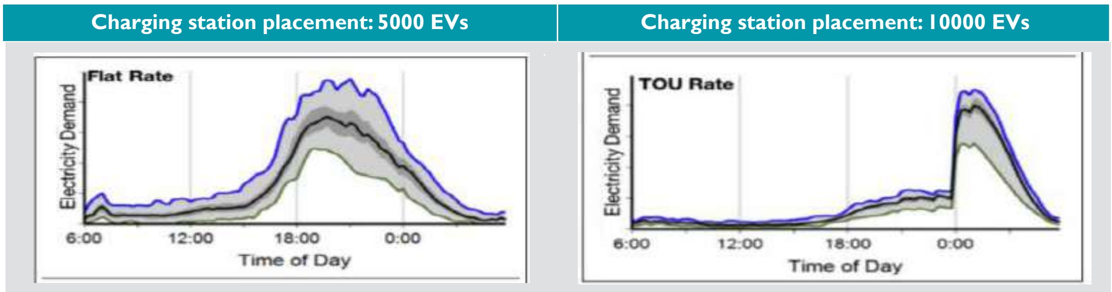
1. The optimal charging station deployment is consistent with the traffic flow heatmap
2. Level 1 charging station is predominant over Level 2 and Level 3. Level 1 service provider must place more charging stations since more of them are required to charge the EVs than the fast charging station
3. Level 1 charging stations are placed evenly across the entire area, while level 3 is more likely to be placed at high traffic locations
4. At the initial stage, Level 1 and Level 2 charging stations are placed more than the next stages. This is because of the fact that service providers must place more charging stations to meet the service coverage constraints. As the number of charging stations increases, however, the service coverage constraint is less of a concern for the service providers since gradually fast charging stations also come up.
5. A key inference of the simulation is that charging stations are clustered. This suggests that service providers prefer clustering instead of spatial separation since consumers using level 3 chargers won't use level 1 and vice versa and hence the competition risk tends to even out if clustered.

3.4 Modelling and simulation to understand the impact of EV charging

As the aggregate load of EVs increase, utilities will need to address couple of issues, primary among them are the following:

1. **Impact on distribution grid infrastructure:** Generally, EV drivers on flat electricity rates tend to plug in to charge their cars upon returning home. If a large number of drivers in a neighborhood return home and commence charging at the same time, there could be a sudden spike in demand which may exceed the capacity of the distribution transformer or other local network infrastructure. Rather than increasing the capacity of the distribution grid, shifting load to times of day when the grid is underutilized is an effective means of providing additional electricity without investing in grid upgrades. This could be carried out using workplace or business charging where EV users can charge their vehicles during low demand hours when the grid is typically underutilized, which would not only increase the utilization factor of the network but would also result in less technical losses in the distribution system. Adequate incentives and policy / regulatory provisions mandating workplace charging could lead to adoption of the same.
2. **Impact on Power procurement:** One of the benefits of EVs is increased electricity sales but with growing penetration of renewables, it is economic to procure cheaper off-peak power over expensive peak power, and shift demand to times of day when electricity rates are lower. In addition, as variable renewables increase their share of the power supply, there would be an increasing need to match flexible loads like EVs to available supply.

Figure 13: Comparison of load profile with different EV charging scenarios



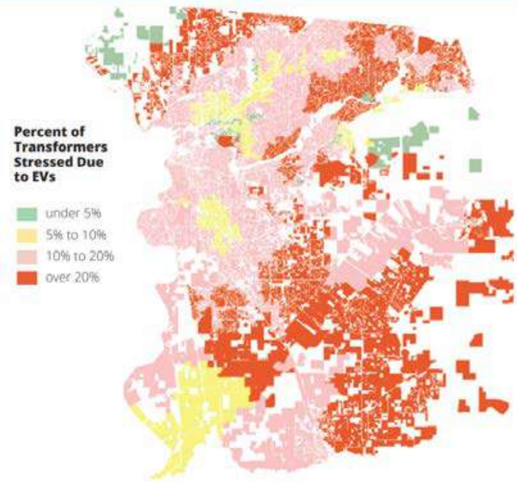
Source: NRECA, US

Thus, utilities will need to adopt several strategies to address these impacts, increase load factor to avoid the need for expanded infrastructure, and align EV charging load with supply. Generally, in the US, more than 70 percent of EV charging occurs at home (ERPI 2018, INL 2015). EVs are generally at home overnight and for long periods of time, allowing flexibility in when the vehicle is charged.

Case Study on EV impact on transformers (Sacramento Municipal Utility District (SMUD))

Sacramento Municipal Utility District (SMUD) has experienced significant DER growth in its service territory over the past decade. To anticipate future necessary investments required in its network and prepare itself for increased integration of EVs, the utility commissioned Black & Veatch to provide an integrated forecast of customer-side DER growth and estimate costs for any necessary distribution infrastructure upgrades. The study was conducted by SEPA and Black & Veatch, under a high-penetration DER scenario that included 240,000 EVs by 2030. It was assumed that nearly all EV owners would take advantage of SMUD's current EV rate, which encourages customers to charge between midnight and 6am, and this led to significant load increases during these night-time hours that caused the transformer overloads. It was found that:

Figure 14: EV Impact on Transformers in SMUD Service Territory through 2030



Source: Smart Electric Power Alliance, Black & Veatch, and SMUD, 2017

- Up to 17 percent (12,000) of SMUD's service transformers may need to be replaced due to overloads
- Cost of replacement of service transformers would be at an average estimated cost of $7,400 per transformer.
- EVs would have considerable impact by 2030, and the transformer replacement costs translated to about $100 per EV.
- The study also brought out findings on % of transformers which would likely be stressed due to increased uptake of EV charging. The adjoining map indicates that there would be significant number of transformers stressed in the utility area due to uncontrolled charging.

SMUD inferred that if EV charging is concentrated during a limited number of hours, managed EV charging was recognized as one potential solution to reduce transformer stress and defer upgrades (and possibly provide other grid services), as long as the cost of the communications infrastructure is low enough that managed charging can provide a net benefit. Another solution is rate-based incentives for EV owners to charge during the middle of the day to absorb excess PV generation. Moreover, The Sacramento Municipal Utility District estimates that one-way smart charging will reduce grid upgrade expense by over 70%.

Note: These results represent an EV adoption scenario that is 30-60% higher than SMUD expects in reality, and total upgrade costs could be lower if cheaper mitigation solutions are available. Today, only about 30% of EV owners in SMUD's territory take advantage of the EV rate, so charging may not be as concentrated during night-time hours as this analysis assumed. Each utility will need to conduct its own analysis to determine where EV adoption is likely to occur and how charging behavior affects utility infrastructure costs.

Managed charging can be broadly sub-divided into two main categories: **Passive** and **Active** managed charging. **Passive managed charging** relies on load control through behavioral changes in consumers. The energy service provider attempts to influence the EV charging behavior by incentivizing certain behavior patterns through predetermined time-of-use rates for charging or other such incentivizing programs.

Active Managed charging involves taking direct control of the charging process through advanced telematics sent from the Load Dispatch Centre (LDC) to the vehicle or the charging station. These signals can then be leveraged by the LDCs through aggregators for providing grid services such as emergency load reduction, regulation or absorption of excess generation of RE sources.

3.5 Uncontrolled charging and undertaking managed charging

3.5.1 Early stage adoption of EVs

A key foundational initiative by utilities in various parts of the world has been to understand the importance of EVs and aiming to raise consumer awareness. This strategy involves adoption of in-house EVs, educating customers through awareness campaigns, and demonstrating use cases and applications.

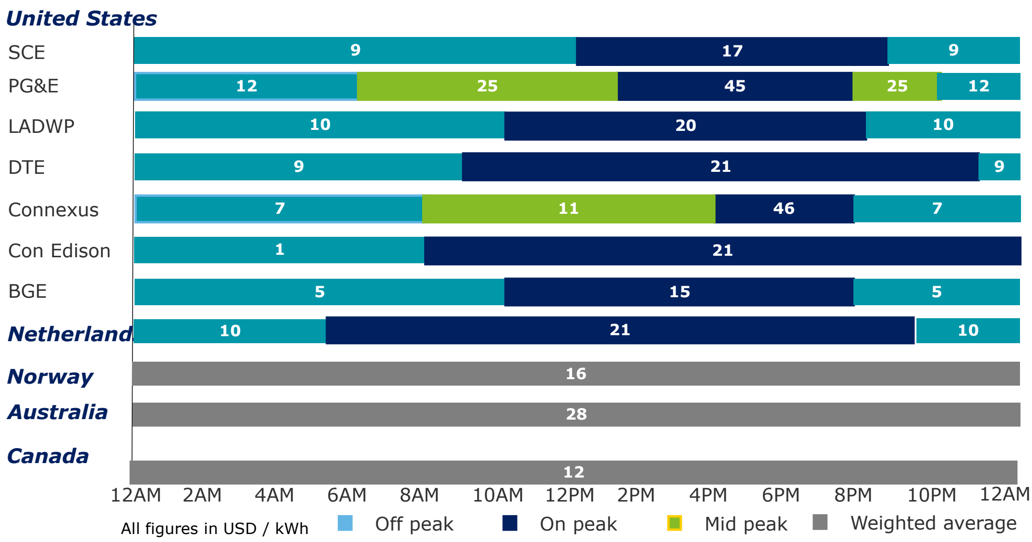
Table 14: Case studies on initiatives taken for early stage adoption of EVs

Case study	Details
Florida Power & Light, Florida	In 2006, FPL became the first energy company in the nation to place a medium-duty hybrid-electric bucket truck in service. Today, its clean vehicle fleet includes 1,849 biodiesel-powered vehicles and 493 electric and hybrid-EVs, which use up to 60% less fuel and reduce exhaust emissions up to 90%. FPL promotes the use of EVs for its company, employees, and customers. To help advance the adoption of clean driving technology in Florida, the company participates in events and offers information on its website: FPL.com/EV, where customers can learn more about EV benefits, charging requirements, workplace charging, and public charging options.
Tampa Electric Company, Florida.	Aside from a website that includes resources for types of EVs, charging options, links to U.S. Department of Energy cost calculators and a map with charging infrastructure locations, Tampa Electric is the first electric utility in the country that offers an innovative energy education program focused on EV technology.

3.5.2 Passive Management - Offering rebates and special tariffs

Indirect control refers to incentives that can be in the form of price signals, rewards programs, and other methods that incentivize EV users to undertake vehicle charging during off peak periods when the load on the distribution grid is the least. Many utilities in the United States adopt an initial EV specific time-of-use (TOU) rate to influence drivers to shift their EV loads to off-peak times of the day. This is more of a passive/indirect approach but allows customers to reduce their energy bill and encourages EV charging when the grid is under-utilized and under less stress, such as afternoon/night-time hours. Examples of various utilities offering TOU tariffs are highlighted below:

Figure 15: TOU tariffs for EV charging provided by different utilities in US



Source: Tariff schedules, 2019

On average, the weighted electricity price (i.e., time-weighted) ranges from 10-15 US cents per kWh for EVSE operators. Typically, off-peak rates occur overnight and on-peak rates in the morning and evening hours.

Table 15: Additional provisions introduced by utilities providing EV charging tariffs

Case study	Details
Braintree Electric Light Department, Massachusetts	Through its Braintree Drives Electric program, Braintree Electric Light Department encourages customers to attend EV workshops, test drive cars, and acquire EVs. The utility offers customers an $8 monthly credit, the equivalent of about 175 free miles, for charging at offpeak times. Advanced smart meters help the utility collect data on charging patterns and enable the utility to verify customers are charging during off-peak times.
Wrighthennepin Electric Cooperative, Minnesota	This utility offers residential customers two pricing options for charging EVs at home. Customers can choose between a TOU program and a Storage Charge program. The Storage Charge program lets customers charge during off-peak hours and sets the energy rate at $.054 per kWh for that time. For the TOU program, the charging circuit runs through the meter to accurately track the car's charging, and charges the customers according to the time of charging.
San Diego Gas & Electric Company (SDG&E), California	Customers in apartments, condominiums, and workplaces have access to charging stations with an EV rate structure that reflects the hourly cost of electricity. Dynamic Hourly pricing is set the day before, and customers use a phone app to enter their preferences for maximum energy price or/and amount of hours to charge

Source: GTG-RISE research

Some small electric cooperatives in the US offer whole-home and EV TOU rates as shown below:

Table 16: EV charging tariffs provided by cooperatives in US

Cooperative	Rate type	On-peak ($/kWh)	Off-peak ($/kWh)
Berkeley electric	Whole-house	0.239	0.059
Connexus energy	EV	0.455 (summer) 0.345 (winter)	0.073
Illinois	EV	0.085	0.05
Lake region	EV	0.4734	0.0707
Minnesota Valley	EV	0.397	0.065 (summer) 0.049 (otherwise)
New Hampshire	EV	0.23608	0.10468
Randolph Electric	Whole-house	0.4641	0.0546
	EV	0.3642	0.0843

Source: Tariff schedules, 2019

To summarize, indirect control strategies using TOU pricing has the following requirement, benefits and key challenges:

Table 17: Requirement, benefits and challenges of indirect EV control strategies

Particulars	Details
Requirement	If the price signal applies to the EV separately from the rest of the home, a second meter and/or a Level 2 EVSE is necessary for metering
Benefits	• Effective at shifting load to off-peak times • No losses for utility if rates are set so that they reflect the cost of power
Challenges	• Installing a separate meter and/or Level 2 EVSE adds significant cost to the implementation of this strategy. • Owners may have little / no incentive to install a Level 2 EVSE, and the utility misses out on an opportunity to install the equipment necessary for future direct control. • Utility may experience sharper peak at off-peak times if all EV owners schedule their charging sessions simultaneously during off-peak periods. This will necessitate some form of controlled charging from utility side to avoid sharp charging peaks.

3.5.3 Offering incentives for EVSE

National-level charging infrastructure programs have been essential for boosting rapid deployment of charging stations. For example, China, US, France, Japan, and Norway have developed incentive programs for the installation of EVSE. The following is a high-level overview of such programs:

Table 18: Incentives for creating EVSE in different countries

Country	Program	Budget	Mechanism of support
China	• State Grid national fast charging corridors • Regional investments by automakers • City government-funded construction in pilot cities		• State-owned utility programs • PPP • Grants to local governments
Germany	Deployment of 10,000 Level 2 and 5,000 DC fast charging stations	$285 million	Subsidies for 60% of costs for all eligible businesses
Japan	• Next Generation Vehicle Charging Infrastructure Deployment Promotion Project • Nippon Charge Service government-automaker partnership	$1 billion	• Grants to local governments and highway operators • PPP
Norway	Deployment of charging stations through grant scheme from 2009 onwards		Quarterly calls for proposals for targeted projects
UK	DC fast charging stations along major roads in England	$12 million	• Municipalities apply for grants • Grants and tenders administered by public body

Source: Deloitte research

3.5.4 Active Managed Charging for System Stability

As the level of EV penetration increases in the distribution system, impact of EV charging on distribution system load patterns can become significant. Managed charging can help utilities meet the challenge of maintaining network reliability with high EV penetration. As per Smart Electric Power Alliance, managed charging allows a utility or third-party to remotely control vehicle charging by turning it up, down, or even off to better correspond to the needs of the grid, much like traditional demand response programs.

Active managed charging—also called vehicle-to-grid integration (V1G), intelligent, adaptive, or smart charging—allows a utility or third-party to remotely control vehicle charging by any of the following means:

- Modulating the charging by delaying the start/stop of charging period
- Increasing/reducing charging rates which is also called throttling; this leads to change in amount of electricity drawn, or
- The utility can also resort to turning off the charging to better correspond to the needs of the grid at times of high stress.

Accommodation for customer preferences:

As the primary focus of managed charging is for charging of EVs, customers may have concerns about their EV not getting adequately charged. Any managed charging methodology must take into account customer preferences to ensure higher participation. To ensure good implementation of managed charging, customer preferences need to be put at the highest priority.

Utilities can decide which managed charging control strategy to implement based on factors such as customer preferences, level of EV penetration in network, and infrastructure available to implement passive and active controls. While passive charging management can induce customers to shift their EV charging loads, a sudden onset of EV charging loads during the off-peak period can lead to steep surge in load on the distribution transformer at the onset of the off-peak period. Ideally, this concern can be addressed by staggering charging times using an intelligent assessment of charge status of vehicles, obtaining desired departure time of vehicles, the charge rate, and other factors, thus distributing the charging across a wider time window. Overall, there are several benefits of managed charging described as follows:

Table 19: Advantages of EV managed charging

Advantages	Particulars
Improve grid economics	By modulating/varying the charging levels to reflect the grid conditions, managed charging can achieve higher utilization rates, and therefore capacity factor of generation assets (increased charging rates during off-peak period and reduced rates during peak load/overload conditions)
Reduction in emissions	Managed charging can reduce emissions by aligning charging with surplus renewable generation, thereby creating a scenario where excess renewable capacity can be absorbed in the system, such as photovoltaic (PV) production during peak solar hours and wind spikes during off-peak hours.
Reduced stress on the grid	Managed charging can reduce grid stress and maintain grid stability by minimizing charging ramp rates and reducing the strain on local distribution transformers which tend to be overloaded during peak period.
Capex deferral	Managed charging can reduce the need for new peak generation and distribution capacity resulting from EVs charging during peak hours.
Reduction in T&D losses	Modulating the amperes flowing through the charging station can also result in reduction of technical losses in the distribution system
New market opportunities	Capacity and ancillary market services such as frequency regulation and spinning reserves.
Benefits to EV consumer	Economic returns to EV owners by reducing the cost of charging through dynamic rates and potential payments for the supply of ancillary services.

1. Types of managed charging and key requirements for implementation:

One of the most common method to implement managed charging is through Automated Demand Response (ADR). In this case, the utility cuts power to the EV during peak load periods, curtailing load in order to reduce peak demand. Curtailment events may be initiated using a load control switch or a Level 2 EVSE. A standard practice by utilities is to automatically "opt-in" EV users into the demand response program (i.e., users need to contact the utility if they wish to opt out of the program). Utilities can use an ADR approach to limit charging to off-peak hours. The

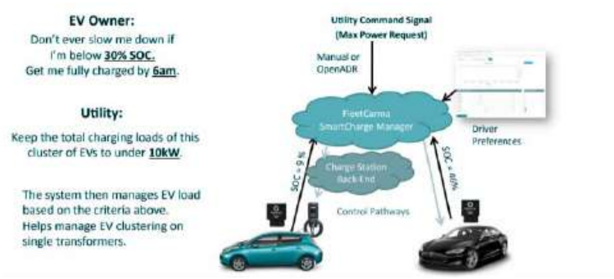
EV charging circuit, in this case, would need to be controlled separately from the rest of the house, using a load control switch or a Level 2 EVSE.

Table 20: Requirement, benefits and challenges of Automated Demand Response

Particulars	Details
Requirement	Load control switch or Level 2 EVSE installation would be required for load curtailment
Benefits	Automated demand response will yield more curtailment than voluntary DR since it is managed by the utility themselves. Presents the opportunity to incentivize installation of Level 2 EVSE for managed charging
Challenges	Load control switches do not facilitate managed charging control strategies

Under active controls, EV consumers provide rights to utilities and energy service providers to manage EV charging using a common communication and hardware protocol made available at the consumer and utility/energy service provider's end. The following are the pre-requisites for implementation of managed charging:

Figure 16: Illustration of basic requirements for managing EV clustering



Source: fleetcarma

- **Setting of User preferences:** A vital input to managed charging is driver preferences for charging. Typically key attributes which act as an input for smart/managed charging from the user perspective are EV owners' time of next departure, minimum charging levels required for next trip, other preferences viz. fast charging till 30% SOC and slow charging thereon, etc.
- **Signaling of utility DR events:** The signals which utility would send to EVs and vehicle chargers combines messaging, or application, protocols (e.g., OpenADR 2.0, OCPP) and transport layer protocols, also known as network communication interfaces (e.g., Wi-Fi, cellular). The messaging protocol contains the instructions that would affect the charging behavior of the EVs i.e. do not charge until after midnight, or charge after 3am etc.—while the network protocol ensures a message gets from point A to point B, but does not provide any instructions or guidance as to behavior of the receiving devices.
- **Assessment of vehicle parameters:** Manage charging will work through an intelligent assessment of charge status of the vehicle, incorporating customers' desired "charge by" times, the charge rate, and other grid factors. The charging time could be distributed across a large time window
- **Determining the charging levels:** Different EV charging levels offer different potential for managed charging. Long- duration of charging with Level 1 or Level 2 provide more time for managed charging events and flexibility for deferring customer charging. Alternatively, the high power demand of DC Fast Charging (DCFC) may be less attractive

- **Communication Pathways:** Communication between the EV user- EV / EVSE, utility-/grid-operator, aggregator, EVSE provider, EVSE and the vehicle itself are critical factors for effective managed charging.

Smart charging can occur in either a centralized (via aggregators) or decentralized manner. In the centralized framework, EV load aggregators act as an intermediary between vehicle owners and grid markets and contract power demand from several EVs. In the decentralized framework, individual EVs respond to market information made available to them.

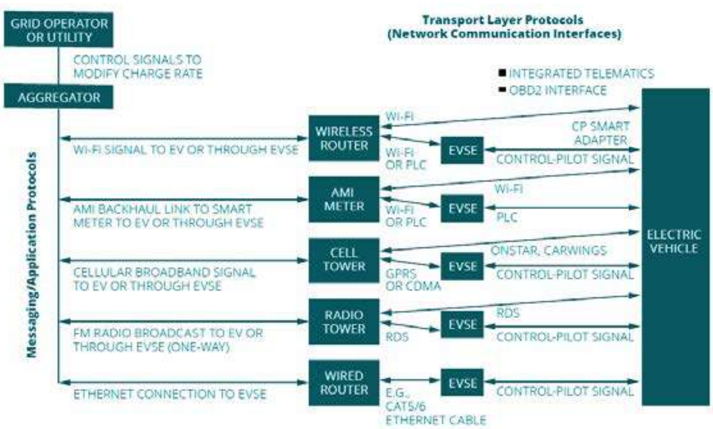
As per SEPA, various modes of transport layer are mentioned below:

Table 21: Communication requirements to implement managed charging

Medium	Details
Wi-Fi	Wi-Fi signal can be sent directly to the EVSE via Control Pilot (CP) Smart Adapter or sent directly to the car by using a telematics link or on-board diagnostic interface (OBD2).
AMI	Utility AMI backhaul link to a smart meter, using Power Line Carrier (PLC) protocols (e.g., Green PHY), and wireless networking protocols (e.g., Wi-Fi, ZigBee) which send signals directly through power lines.
Cellular network	Cellular broadband signal can be sent to the EVSE by using Global System for Mobile communications (GSM), which sends data via code division multiple access (CDMA) low bandwidth wireless connections (data speed requirements for EVSE can also vary, e.g., 2G, 3G, 4G, LTE) or general packet radio service (GPRS). Cellular signals can also be provided to the vehicle through onboard integrated communications
Radio network	FM radio broadcast through a Radio tower to embed digital information directly to the vehicle or the EVSE.
Ethernet	Ethernet also called as Local Area Network (LAN) connection to the EVSE

Telemetry and equipment interoperability are a challenging barrier for managed charging. The main roadblock is in finding a cost-effective way to send communication signals while also being reliable, and customer-friendly. Figure 12 illustrates the links in the chain of communication between the utility and the vehicle.

Figure 17: Communication protocol for managed charging



Source: Smart Electric Power Alliance, Black & Veatch, and SMUD, 2017

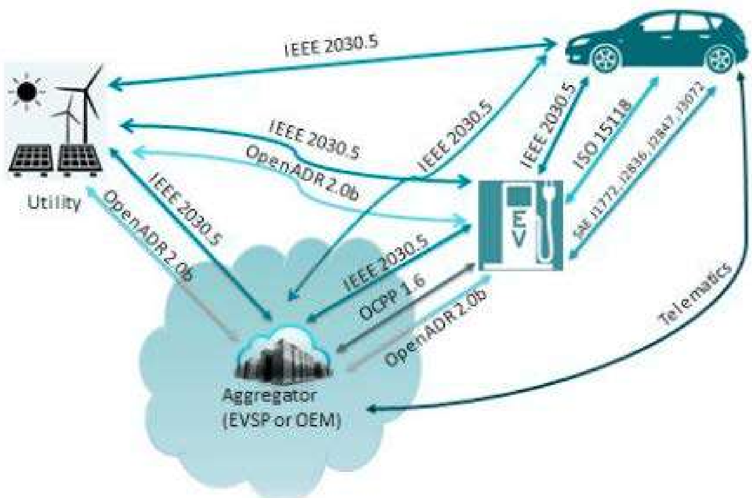
Messaging Protocol: In EV managed charging, messaging protocol signifies the rules, formats, and functions for exchanging messages between **EV, charging station, and**

charging station network. Following are **two types of messaging protocols** widely used in managed charging:

Table 22: Managed charging messaging protocols

Type of protocol	Details
Open source	• For managed charging, it is vital that uniform and non-proprietary communications / messaging protocols are used between the EVSE and EV, for e.g. ISO/IEC 15118 that enables the managed charging functionality in an EV and can give an improved EV consumer participation. • The Electric Power Research Institute (EPRI) is synchronizing a software application (Open Vehicle Grid Integration Protocol) that connects EVSE and EVs to various nodes to allow utilities to more dynamically manage charging activity that could help with a variety of grid applications. Details are given in annexure • The standards followed by the OVGIP are IEEE 2030.5,36 ISO/IEC 15118, and telematics with utility standard interface protocols (i.e., OpenADR 2.0b, IEEE 2030.5) and EV charger application program interfaces (i.e., ISO/IEC 15118, OCPP, and industry applied standard and proprietary APIs) through a common platform.
Proprietary	GPS tagging • Vehicles can be managed through an on-board diagnostic interface (OBD2) which has built-in capabilities, like GPS location software, which can be managed according to the local grid circuit Programming capabilities • Currently multiple EVs already have the ability to program their charging window that would enable the user to align charging with TOU or other EV rates. A more advanced way to strength, these vehicles would for the utility or aggregator to send price, emissions, or grid stress signals directly to the vehicle, so that the EV's charging program could use the information to modify its schedule of charging the vehicle time. • Some examples that are using Proprietary protocol are eMotorWerks JuiceNet, Siemen's VersiCharge platform, and Itron/ ClipperCreek's OpenWay network.

Figure 18: Basic schematic of managed charging



Source: CAISO, 2014, "Vehicle-to-Grid (VGI) Integration Roadmap"

Table 23: Requirement, benefits and challenges of EV managed charging

Particulars	Details
Requirement	Level 2 EVSE, EV capable of managed charging, Communication pathways, networking and messaging protocols, utility readiness, technological partners etc.
Benefits	Allows the utility to match demand and supply in real-time, avoid rebound peaks associated with off-peak structures, and provide charging-as-a-service to members. Opens the potential to aggregate EV resources for V2G services.
Challenges	Utility takes on the responsibility of providing EV charge to member expectations. Requires various user and grid inputs Currently technology is still under development and only a number of pilots have been done

2 Case studies on managed charging implemented by utilities

Case study - Maui Electric, Hawaii[10]

Maui Electric offers residential customers a discounted TOU rate from 9 a.m. to 5 p.m. when solar and other renewable energy options are readily available. This rate requires customers to install a separate meter at no cost to the customer.

TIME-OF-USE CHARGES

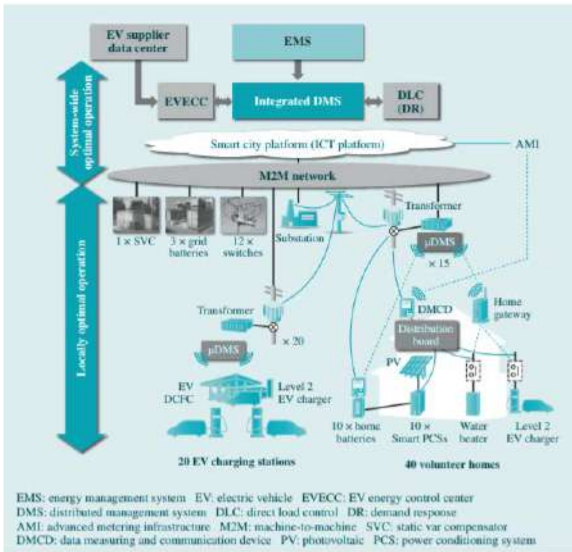
On-Peak Period – per kWh 39.2152 ¢/kWh

Mid-Day Period - per kWh 14.0098 ¢/kWh

Off-Peak Period – per kWh 38.1370 ¢/kWh

Through the JUMPSmartMaui pilot with Hitachi and Nissan Leaf owners, volunteer drivers were provided with EV-Power Conditioning Systems (EVPCS) in their homes. The purpose of this EVPCS system is to allow utility operators to manage EV charging to balance generation and power demand

Figure 19: Managed charging schematic for Maui electric



System overview

The project aims to improve the convenience of using EVs in order to encourage their adoption by installing EV direct-current fast chargers (EV DCFCs) at five sites around Maui, and subsequently at an additional 15 sites. The sites were selected based on an analysis of traffic patterns and distances from homes, offices, and tourist sites.

[10] *http://www.hitachi.com/rev/pdf/2014/r2014_08_102.pdf*

[11] *Source: https://www.mauielectric.com/products-and-services/electric-vehicles/electric-vehicle-rates-and-enrollment*

https://www.mauielectric.com/documents/billing_and_payment/rates/maui_electric_rates_maui/maui_rates_tou_ri.pdf https://www.mauielectric.com/a/5052

To provide the island with an energy infrastructure that does not depend solely on fossil fuels, it also used the EVs as batteries to absorb excess energy and to stabilize a grid that has a large installed capacity of renewable energy. In addition to installing EV DCFCs, the project also included systems for the home (standard EV chargers, water heaters, and PV power generation) and large grid batteries.

The EV Energy Control Center (EVECC) described below provides integrated energy management for the island and exchanges information with an integrated distributed management system (DMS) and energy management system (EMS) located in the control room at the Maui Electric.

Hitachi supplied:

1. variable-output EV DCFCs with direct load control (DLC) function and the ability to be coordinated with existing generation plants.
2. a charging management system that supports the EV DCFCs

Operation of charging management system

The charging management system works as per the following constraints:

1. allocates a total output capacity of 60 kW between the vehicles, with the precedence for charging being determined by the order in which they were connected. Once the charging of one vehicle is complete, the charging of the next vehicle commences.
2. Minimize excessive disconnections to maintain supply and demand balance.
3. Complete control operations within a fixed time.
4. Minimize disruption to consumers caused by restricting power demand.

The charging management system, which performs integrated management of the chargers via a machine-to-machine (M2M) network, collects information on charger operation and provides information via web screens to EV users. Users can choose an appropriate time to charge their EV by accessing the web screens to check whether sites are in use or undergoing maintenance.

The EVECC acquires information from the integrated DMS about the balance of supply and demand on the grid, and state of charge (SOC) information (how much power remains in the EV batteries) from the EV supplier's data center. It can also perform a load shifting to balance supply and demand for electric power.

1. First the integrated DMS obtains information about the supply and demand for electric power, including renewable energy, from the EMS at the power company's control center,
2. The DMS then uses this to produce a schedule of when excess energy is likely to be available.
3. Next, the integrated DMS and EVECC exchange information about the supply and demand balance and EV charging schedule so that the EVECC can revise this schedule.
4. Finally, the EVECC controls when EV charging should start and end to utilize the excess energy.

5. Micro distribution management systems (μDMSs) installed on low-voltage transformers monitors the voltage on the low-voltage grid. When a μDMS detects a fault or overload condition of distribution network, the initial response to protect the concerned DT is to issue power control commands to smart power conditioning systems or to turn off / reduce EV charging to avoid voltage deviations. In some cases, the supply and demand balance is maintained by using the DLC (Direct Load Control) function to disconnect consumer loads such as water heating or EV charging.

Source: Hiraoka et. al., 2014, "Island Smart Grid Model in Hawaii Incorporating EVs", Hitachi Reviews.

Case study - Southern California Edison

SCE utilized a workplace charging pilot[12] which included the following options:

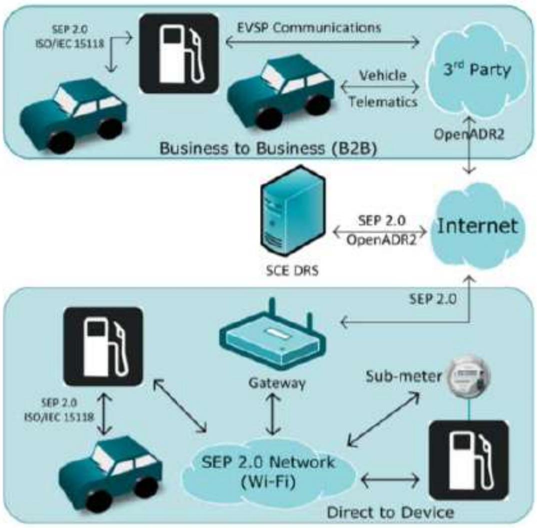
1. allowing users to have no charging disruption;
2. allowing for peak demand curtailment from a faster Level 2 to a slower Level 1 charging rate;
3. allowing drivers to be entirely curtailed during a demand event.

Even if an EV owner who has registered for load curtailment, he/she can opt out through a manual override feature which would cause the EV to charge as-usual.

SCE used OpenADR 2.0b and OCPP for the communication signals. The Pilot evaluated two possible 'paths' of over the internet communication that could be deployed for residential EV load management programs: Direct and Business to Business (B2B)

1. Demand response server: The server provided an operator portal that was common to both protocols and could be used to manage events, collect, display and provide data, provide the required customer notification (email, text, voice mail) and opt-out capabilities
2. Direct communication to devices: SCE communicated Demand Response signals directly to EVSEs via an internet gateway (GW) that was an Ethernet/SEP 2.0 client on the Wide Area Network (WAN) side and Wi-Fi access point/SEP 2.0 server on the Local Area Network (LAN) side. EVSEs and apps polled the GW server for events and the GW client in turn polled SCE's SEP 2.0 DRS

Figure 20: Managed charging schematic for SCE



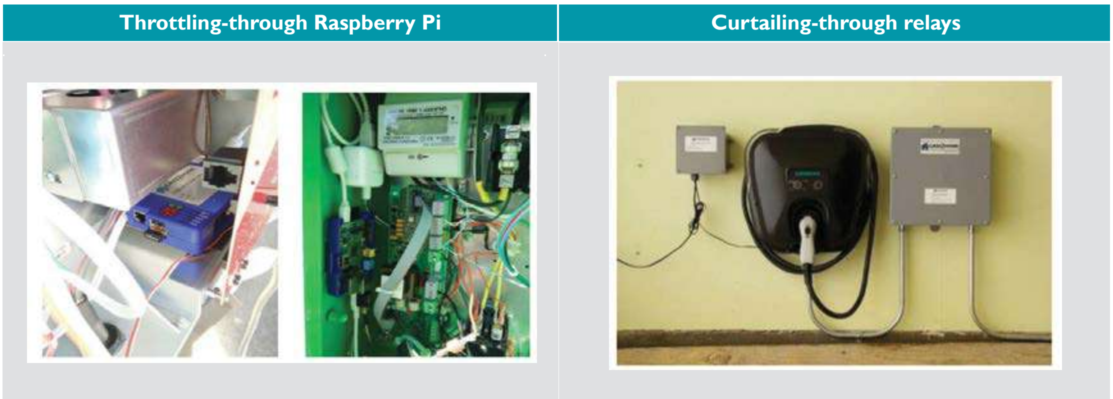
[12] http://www3.sce.com/sscc/law/dis/dbattach5e.nsf/0/B2DF49B3487114808825 7FBE0073125F/$FILE/R1309011-A1410014-SCE%20PEV%20Smart%20Charging%20Pilot%20Final%20Report%20.pdf

for DR events and other SEP 2.0 communications. Polling rates were set for 5 minutes. Similarly, meters posted data to the GW server and the GW server posted meter data to SCE's SEP 2.0 server. Posting rates were 5 seconds.

3. Integration with EVSEs and meters for Demand response: SEP 2.0/Wi-Fi was integrated into the level 2 EVSEs and meters by selecting a suitable implementation partner. This was used to communicate the signals sent by DRS to the vehicles / EVSE

   A Raspberry Pi, a programmable controller that provides a set of GPIO (general purpose input/output) pins that allow to control electronic components, with attached Wi-Fi dongle was used for the communications and DR integration. This allowed SCE to throttle / reduce the power provided by the EVSE to the EV. On other EVSE where the Pi could not be attached, a relay already integrated into the EVSE was used to curtail the charging completely.

Figure 21: Key Hardware Components of PEV Smart Charging Pilot



Source: Southern California Edison, 2016, "Plug-in Electric Vehicle (PEV) Smart Charging Pilot"

4. Business to business communication: In this a 3rd party (e.g., an aggregator) enrolls in a DR program and manages loads based on SCE called events
5. Electric vehicles: EV's used in this pilot were tested for being capable of both telematics communication and load management (e.g., the ability to stop charging remotely). Some vehicles tested already had these capabilities, while others were engineering (e.g., prototype) vehicles provided by the OEMs, with either communications, controls, or both.

3.6 Regulatory interventions for enabling EV charging

There are several regulatory barriers to the deployment of EV charging infrastructure including permitting of charging infrastructure, the lack of a technical standard for charging infrastructure, policy uncertainty, regulation regarding recovery of EV-related investment by utilities. To overcome these barriers, policies are needed to create a conducive environment for private sector investment in charging infrastructure — whether it be modifying building codes, streamlining permitting, or deciding a standard in consultation with OEMs, for example.

Based on a review of international case studies, four main regulatory interventions have been identified. These are as follows:

- Cost recovery of network upgrades necessary for supporting EV charging infrastructure
- EV charging specific tariff
- Creating a managed charging framework
- Market based framework for enabling EV and other DR providers to participate in ancillary services

These regulatory interventions focus on ensuring that utilities are able to invest and recover the costs in creating a back-bone for EV charging stations to be connected to the network. Further, it ensures that consumers are able to charge EV through utility network at affordable and competitive rates. Lastly, it allows utilities to manage the charging behavior of EV consumers to ensure network reliability and enables a market framework for EVs to participate in demand response. These interventions are highlighted in detail in the following sections.

3.6.1 Cost Recovery of Network Upgradation and EVSE Infrastructure

Utilities play an important role by undertaking investments in network upgrades and adopting tariff structures for supporting EV charging ecosystem. Regulators can facilitate utility network upgrades for grid modernization through providing utilities with clear channels of cost recovery and guidance on required technologies.

Utility investments in infrastructure to support EVs, including system upgrades, dedicated meters, and workplace or public EVSE, could be funded by distributing the costs across all customers. In the US, this practice is known as "rate-basing." Rate-basing investments add only a small amount to customer electricity bills, and regulatory agencies may encourage these investments due to their potential to increase utilization of the electric grid and incentivize wider adoption of EVs and drive down rates for all ratepayers.

There are several reasons why rate-basing upgrade costs (if any) – at least for an initial period – make sense.

- Rate-basing costs is much simpler than trying to ascertain individual customer responsibility for an upgrade
- Imposing distribution facility upgrade costs on specific consumers may discourage them from purchasing an EV or "smart charging" equipment that could actually benefit the grid by facilitating off-peak load and improving grid utilization.
- Impact of EV charging on the distribution system has been minimal and hence the investments if spread across all consumers will also have minimal impact.

The state of California issued the state policy goals under Assembly Bill (AB 32) to reduce greenhouse gas emissions and the related ARB Scoping plan which includes a comprehensive strategy to reducing greenhouse gas emissions from the transportation sector. Electrification of vehicles is a critical component of the ARB's 2008 Scoping Plan. Electric Tariff Rules-Rule 15 (Distribution Line Extensions) and Rule 16 (Service Line Extensions) pertain to grid equipment used by multiple customers, for example, a transformer serving multiple homes and network equipment used by just one customer respectively.

As per California Public Utilities Commission (CPUC), the rationale for adoption of rate basing of EVSE is highlighted below:

Table 24: Rationale behind adoption of rate basing by CPUC

Particulars	Rationale
Utility expenses vs customer expenses	An upgrade to equipment which has the potential to serve multiple customers is generally considered a utility expense and the associated cost is borne by the general body of ratepayers and not just by the EV customer or just by the group of neighbors being served by the transformer.
Upgrade as a system asset and Rule 16 provisions	The cost to replace a shared distribution transformer, due to projected impact of additional loading by EVs, would be considered a total system asset and, as a result, should be included in rate base. On the other hand, the cost to replace an existing customer-specific service transformer would be at the customer's expense. A commercial or public charging station is hence considered as a system wide asset.
EV as a new and permanent load	The load profile created by EVs is similar to that created by other large residential appliances, such as large portable air conditioners and hence it cannot be considered as a temporary load created by specific customers.
Improved system utilization and reduced losses for managed charging	• Incremental EV load on a larger scale has the potential to yield improved electricity system asset utilization in the long-term. Benefits of the same would accrue to all customers of the utilities • On a large scale EV charging occurring during off-peak periods could actually reduce the price of energy for all ratepayers which would have otherwise been incurred by utilizing expensive peaker plants in on-peak periods. The benefits of the same would be realized by all customers
Residential level upgrades	Any expenses incurred over and above the standard residential allowances, if any given to EV owners, would be rate based provided that the additional expenditure pertains to only basic and necessary investments
Adherence to overall state goals	Adoption of EVs is based on California State's goal to reduce greenhouse gas emissions through the electrification of the transportation sector and hence any investments in achieving the same is as per the state goals.

Source: CPUC

The above provisions apply to utilities viz. Southern California Edison, Pacific Gas & Electric and San Diego Gas & Electric. However, the aforementioned provisions are construed as initial steps to build out charging infrastructure and help determine the best practices for long-term network growth.

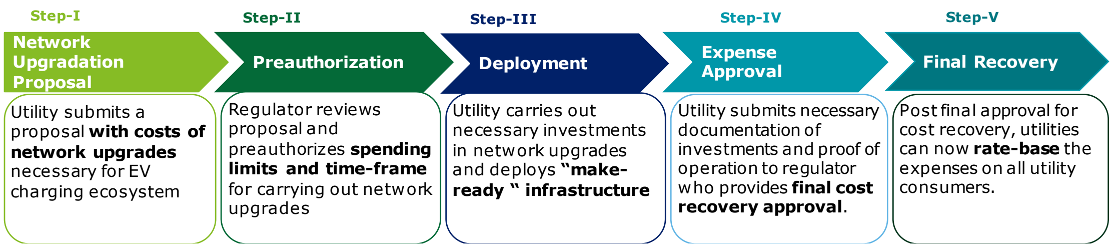
There are several U.S. utilities that have moved towards more progressive planning for electric vehicles, including deploying ratepayer – funded public charging infrastructure in order to accelerate the slow pace of growth in this sector. These programs are widely viewed as initial steps to build out charging infrastructure and help determine the best practices for long-term network growth. These programs differ in the scale, relationship with third-party EVSE provides, specific charging circumstances (e.g., home, workplace, multi-unit dwelling, etc.). However, although rate basing has been approved, regulators have only allowed a pre-determined number of charging stations, indicating that they are hesitant to let utilities fully control the market and instead let compensation be the driving force for expansion of charging stations.

3.6.2 Rate-basing of "Make-Ready" Infrastructure

Utilities are adopting a range of approaches while undertaking investments in network upgrades necessary for facilitating EV charging services. Supported by regulators, utilities in the US have taken an approach of investing in "make-ready" infrastructure where utilities set up the necessary infrastructure required for EV charging services providers to install charging stations. "Make-ready" infrastructure may include components such as necessary transformer and transformer pads, new service meter, new service panel, associated conduit and conductor necessary to connect each piece of equipment, and it can also include Smart Grid Devices.

While the "make-ready" infrastructure is owned by utilities, the EVSE is owned by charging service providers. A process chart followed by Department of Public Utility of Massachusetts for allowing cost recovery of Eversource utility's $ 45 million investment plan for development of EV charging infrastructure is as follows:

Figure 22: Process Flow for Cost Recovery



Source: Department of Public Utilities, Massachusetts

Regulators in India can explore mechanism/design to accommodate distribution utilities to recover cost associated with "make-ready" infrastructure in their Annual Revenue Requirement (ARR) filings.

> Through the Charger Ready Program, SCE installs and covers the costs for make ready charging infrastructure , while participants own, operate and maintain the charging stations. The program also provides rebates towards the purchase of charging station. The Charge Ready Program will help grow the transportations electrification market by installing electric infrastructure at customer sites to support charging.
>
> In the first phase, SCE installed approximately 1,000 EV charging points at over 60 sites in SCE's territory, including workplaces, public parking lots, hospitals, destination centres and apartment and condominium complexes were built. In Phase 2, which is yet to be approved, SCE shall support the installation of "make-ready" infrastructure at workplaces, other public locations and multi-unit dwellings, and provide rebates to cover a portion of the EV charger costs. Close to 32,000 charging ports at approximately 3,200 sits shall be built. At least 30 percent of the charging infrastructure shall be deployed in disadvantaged communities. SCE shall also be launching a number of other Charge Ready Programs and Pilots that support medium and heavy duty trucks, transit buses, port equipment and other industrial vehicles, as well as public and home-based charging for cars.

3.6.3 Tariff Framework for EV Charging.

Tariff for EV Charging at Utility Owned EVSE Infrastructure

Several regulators in US allow utilities to own charging stations in-order to avoid stifling of market competition except in particular cases where provisioning of charging service is an issue such as in disadvantaged communities. In cases where there is no restriction on utilities to own charging infrastructure, utilities have set-up charging stations along with the necessary grid facing infrastructure. In this case, utilities are allowed to recover the cost of "make-ready" infrastructure and EVSE through rate-basing.

For example, the CPUC allows "PG&E to include the EVSE it owns in its rate-base, because it will be utility property that is used and useful in rendering utility service". Similarly, SDG&E's "Power Your Drive Program" is a three-year, $45 million program to install, own, and operate 3,500 level 2 stations at workplaces and multiple unit dwelling locations. The projected increase in consumer electric bills is 0.02% per year, or about $0.18 annually.

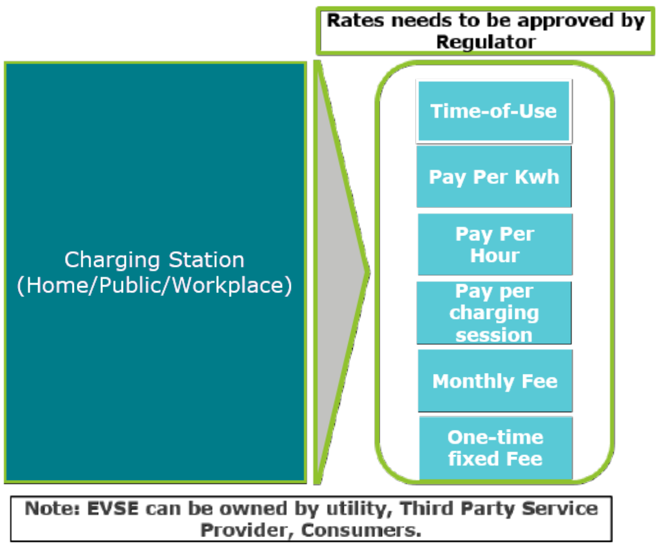
Florida Public Services Commission – Cost Recovery of EVSE

In November 2017, the Florida Public Service Commission approved a Duke Energy Florida settlement to allow the utility to own and operate an EV charging network with a minimum of 530 Level 2 and DC fast charger ports. Key details[13] of the pilot program include the following:

1. The Commission approved that DEF may incur up to $8 million plus reasonable operating expenses
2. At least 10 percent of the EVSE ports must be installed in low income communities
3. The EVSE program will be a pilot program ("Pilot") for five (5) years.
4. Electricity pricing: Where EV drivers make purchases directly from DEF when using the EVSE, said drivers will pay the appropriate Commission-approved rates/prices for energy use at the EVSE
5. **Regulatory treatment:** DEF shall be authorized to defer the recovery of its EVSE program capital costs and operating expenses (full revenue requirements) to a regulatory asset that will earn DEF's AFUDC rate. Revenues generated through the EVSE shall offset the amount of the costs to be deferred to the regulatory asset. At the time DEF makes the filing described, but in no event sooner than the expiration of the Term, DEF will be authorized to **recover the amount of the regulatory asset over a four-year period through a uniform percent increase to the customer, demand and energy base rate charges**
6. The EVSE shall be subject to a depreciation rate of 20 percent.

Utilities can decide to recover the full cost of EVSE infrastructure through an increase in fixed charges; a mix

Figure 23: Charging Rate Structure



[12] http://www.floridapsc.com/library/filings/2017/09951-2017/09951-2017.pdf

of fixed and variable charges from EV charging services; or fully from EV charging services. In all cases, regulatory approval is required. A range of options can be considered for tariff rate structure design as shown in alongside.

In some states in the US, utilities have been relatively more active with EV development as a response to regulatory or policy activity. States such as Washington, Minnesota, Florida, Oregon, and California have all enacted legislation encouraging utilities to file applications for charging infrastructure with their public utility commissions. In 2015, California also enacted SB 350, which instructed the California Public Utilities Commission (CPUC) to direct the six in-state investor-owned utilities (IOUs) to submit programs that "accelerate widespread transportation electrification" to meet state goals. Similarly, the state of Minnesota required all public utilities to file an EV tariff with the commission.

Case Study – Tariff framework for EV charging in Minnesota

Under the Minnesota Statute 216B[14].1614 "ELECTRIC VEHICLE CHARGING TARIFF", by February 1, 2015, "each public utility selling electricity at retail must file with the commission a tariff that allows a customer to purchase electricity solely for the purpose of recharging an EV." It has been highlighted that the tariff must:

- contain either a time-of-day or off-peak rate, as elected by the public utility;
- offer a customer the option to purchase electricity:
  - from the utility's current mix of energy supply sources; or
  - entirely from renewable energy sources,
- be made available to the residential customer class.
- The commission shall, after notice and opportunity for public comment, approve, modify, or reject the tariff
- The commission highlighted several conditions for the tariff to be approved which include that:
- The tariff should appropriately reflect off-peak versus peak cost differences in the rate charged
- The tariff should include a mechanism to allow the recovery of costs reasonably necessary, including costs to inform and educate customers about the financial, energy conservation, and environmental benefits of EVs and to publicly advertise and promote participation in the customer-optional tariff
- provide for clear and transparent customer billing statements including, but not limited to, the amount of energy consumed under the tariff; and
- incorporate the cost of metering or sub-metering within the rate charged to the customer.
- The utility may at any time propose revisions to a tariff filed under this subdivision based on changing costs or conditions.

[14] *https://www.revisor.mn.gov/statutes/cite/216B.1614*