Electric Vehicle Infrastructure: Homework for Electric Utilities

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1. Introduction

As electric vehicle (EV) ownership expands in the coming decade, electric utilities have their work cut out for them. EVs will not only be in use at private residences, but also for publicly and privately owned fleets of light-duty and heavy-duty vehicles. New infrastructure will be required to support commercial EV charging stations for both individual EVs and fleets; EV chargers must be enhanced to better work with the electric energy grid; and electric utilities must consider infrastructure and energy cost recovery.

EVs also present opportunities for electric utilities, including grid support during underfrequency events and climate-friendly disaster recovery efforts. For electric utilities to embrace these benefits, they must begin working to prepare the grid for expanded EV ownership today.

This whitepaper discusses specific ideas that electric utilities can use to create an EV preparedness strategy so that they are ready for the widespread integration of EVs.

2. Classes of Electric Vehicle Chargers

Three classes of EV chargers are available today:

- Level 1: 120 Volts and 15 amps, single phase AC. Level 1 chargers can deliver 1.8 KWH (5.4 miles) per hour.
- Level 2: 240 Volts and 40 amps, single phase AC. Level 2 chargers can deliver 9.6 KWH (28.8 miles) per hour.
- Level 3: 480 Volts and 50 amps, or 100 amps or 200 amps, three phase AC. Level 3 chargers can deliver 42 KWH (126 miles), 84 KWH (252 miles) or 167 KWH (504 miles) per hour.

Level 1 and Level 2 chargers should be classified as either residential chargers or long-term parking chargers, i.e. for commuters who park their EVs in one location for an entire 8-hour workday. Because of their slow energy delivery time, Level 1 and Level 2 chargers are ineffective for recharging EV batteries during long distance travel and disaster recovery conditions.

Level 3 chargers should be classified as commercial chargers. These chargers provide energy at a much faster rate, making them the best option for neighborhood or highway charging stations, long-haul truck charging stations, and fleet charging centers.

3. Next Generation EV Charger Settings

Next generation EV chargers must be designed with multiple functions in mind, not simply charging an EV. Functions must include charge mode, standby mode, and grid support mode. Smart chargers would be capable of automatically switching between these functions based on predetermined settings, such as energy availability or grid frequency.

EV charger functions would also be dependent on the level of battery charge. For example, if an EV battery is below 25% charged when plugged in, the charger would automatically enter charge mode until the EV battery reaches 75% charge capacity, and then transition to standby mode. If the EV battery is over 75% charged, the charger would remain in standby mode until excess energy is available on the grid. Only batteries that are charged to 50% capacity or more would be switched to grid support mode when needed, such as during underfrequency events.

4. Residential EV Charging

A single Level 1 charger can be easily accommodated in single family residences with 100 amp or 200-amp circuit breaker panels. Level 1 chargers should only be purchased by consumers who plan to use their EV on short, daily commutes, rather than long distance travel, even occasionally. Level 1 chargers are also the best option for multifamily residences, such as apartment or condominium complexes, that want to accommodate multiple EVs.

A single Level 2 charger can most likely be accommodated in single family residences with 200-amp circuit breaker panels. Apartments, condominiums, and other multifamily residences with 100-amp circuit breaker panels will require modifications to accommodate Level 2 chargers.

An electrical inspector must approve the installation of a 200-amp circuit breaker panel when it is installed to replace a 100-amp circuit breaker panel. This installation will require other changes to residential wiring that potentially increase the load on the customer's service transformer. The electric utility should verify the sizing of the customer's service transformer is appropriate for this change.

When two or more EVs are owned by residents of a single-family residence, both EVs cannot be charged at the same time. Charging both EVs at the same time will cause the main circuit breaker to trip. When molded case circuit breakers trip repeatedly due to overloads, the trip value of the molded case circuit breaker drops below the stated value, creating a circuit breaker that is more likely to trip at lower energy demands. To address this issue, either the circuit breaker panel will need to be rewired or a selector switch will need to be installed. A selector switch can automatically change the flow of electric energy from one EV charger to the other once it senses that the EV battery has reached a certain threshold, such as 75% charged. Ideally, the EV owner can set their preferred threshold.

5. Commercial EV Charging

Within the next decade, commercial charging stations will be equipped with separate Level 3 chargers for light-duty vehicles and heavy-duty vehicles. For light-duty vehicles, commercial charging stations must have 480 Volt, 200 amp, 167 KVA, three phase AC chargers. For heavy-duty vehicles, 480 Volt, 600 amp, 500 KVA, three phase AC chargers must be installed.

Commercial charging stations for light-duty EVs should be designed to charge 12 to 20 EVs at the same time. This means that electric utilities will need to provide between 2,000 KVA and 3,500 KVA of capacity for most light-duty EV charging stations. With 20 charging stations, a commercial charging station will be able to accommodate 800 EVs per day in warm weather and 600 EVs per day during cold weather, so long as each EV requires 80 KWH to charge the batteries. The number of charging stations for light-duty vehicles should be equal to the number of gas stations that are in the area.

Commercial charging stations for heavy-duty EVs should be designed to charge 20 EVs at the same time. This means that electric utilities will need to provide 10,000 KVA of capacity for heavy-duty charging stations. In effect, each heavy-duty commercial charging station will require a dedicated feeder from a neighborhood substation. The number of charging stations for heavy-duty vehicles should be equal to the number of gas stations for long haul trucks in the area.

6. **Renewable Energy Considerations**

In the early days of electric vehicles, electric utilities recommended that EVs be charged during off peak hours, such as late at night. However, most renewable energy is produced during daylight hours. With the rapid expansion of renewal energy sources, excess energy is available during April, May, September, and other times when solar panels and wind turbines produce more energy than consumers demand. Rather than turn solar panels off and feather wind turbines, EV chargers should be designed to activate charge mode whenever excess energy is available. When less energy is available, EV chargers will then shift to standby mode.

7. **Maximize Daytime Energy Availability**

To maximize availability of EV chargers during daylight hours, when EV owners are often away from their residential chargers, electric utilities could develop partnerships with transit authorities, specifically owners of light rail systems. A light rail parking lot can be equipped with 300 Level 2, eight-hour, 10 KWH next generation chargers that EV owners connect to when they park their car on the morning commute. Next generation chargers will detect EV battery charge level and energy availability of the grid and adjust the charger function accordingly.

By partnering with light rail transit authorities, far fewer additional electric utility facilities will be needed to charge EV batteries. This is because the electric load on light rail facilities is intermittent, and the electric energy connection can be used to charge EVs when trains are not using the facilities. Many major cities across the US have existing light rail transit systems with large parking lots for commuters.

Parking garages also present an opportunity for partnership with electric utilities. By installing only three Level 3, 30-minute, 100 KWH chargers, and providing valet service, a parking garage can charge 300 EVs in one 8-hour workday. This also creates job opportunities for valet drivers. Similar arrangements can be established at shopping centers, hospitals, or anywhere drivers park for 30 minutes or more at one time.

To maximize the effectiveness of Level 2 chargers in parking lots, EV owners should be charged for dwell time (similar to demurrage charges), as well as for energy, when they are parked over a maximum number of hours. Commuters would not be charged for dwell time between the hours of 7 am and 6 pm at light rail and transit center parking lots. Outside of these hours, and at non-commuter parking lots, dwell time should be factored into EV charging prices. Dwell time charges will increase the number of EVs that can be accommodated.

8. **Fleet EV Charging**

Both publicly owned and private vehicle fleets will be converted to EVs in the coming decade. Transitioning these massive fleets to EVs will require an immense build out of EV charging infrastructure.

EV bus fleets, heavy-duty EV truck fleets, and rental car charging stations should be designed to charge 50% of EVs dedicated to that specific location in 8 hours. In long haul applications, the number of EV charging stations should be increased when EVs are expected to require 75% charging on a daily basis. This means that electric utilities will need to provide between 2,000 KVA and 10,000 KVA of capacity for fleet charging stations.

Electric utilities should begin preparing today for the increased charging infrastructure that will be needed to power large fleets of EVs. Facilities, such as new transmission lines, distribution lines, and substations, will require many newly manufactured components: power transformers, circuit breakers, cables, etc. Power transformers can take 52 weeks or more to manufacture and deliver to a job site. Circuit breakers and structural components can take 12 to 26 weeks to manufacture and deliver. This does not include the planning and development phase of the project.

Electric utilities need to begin developing plans for facility upgrades 36 to 48 months before the upgrade will be needed. If electric utilities continue to custom build each facility, they will need five to ten years to build enough new substations and transmission and distribution lines to provide energy for chargers for EV fleets.

9. EV Charging at Travel Destinations

Travel destinations attract millions of tourists during their busiest seasons. Some visit for the day; others may spend a week or more away from their homes. These destinations need to invest in fast charging options to accommodate the peak number of daily and weekly tourists in addition to year-long residents.

The number of commercial charging stations at travel destinations will be a function of the number of hotel rooms. For example, Atlantic City, New Jersey with a population of 276,000 people and 22 large hotels with 20,000 sleeping rooms will require more commercial charging stations than Toledo, Ohio with a population of 266,000 people and 17 hotels with 2,000 sleeping rooms. Plus, the number of commercial charging stations will need to accommodate the number of travelers expected at peak travel times, such as holiday weekends.

A battery with 100 KWH of energy will allow EV owners to travel 300 miles between charging stations. At 60 miles per hour, travelers can drive for five hours before charging. When charging stations are near restaurants, travelers can use charge time to eat a relaxing meal. Driving from New York City to Orlando, Florida (1,200 miles) will require at least four stops to charge batteries in an EV.

10. Charging EVs in Cold Weather

Battery performance and charge time are affected by ambient temperature. During cold weather, driving range is reduced and charge time is increased. When heaters are in use in the passenger cabin, driving range can be reduced by 45 miles during a three-hour trip. Temperatures below 20°F can reduce driving range by 20% and increase charge time by 25%. This means that in cold weather, driving range can be reduced from 300 miles to 200 miles. In cold weather, it will not be advisable to drive an EV from Portland, Oregon to Leavenworth, Washington, about a 300-mile trip, without stopping to charge the battery.

When extremely cold weather causes reduced battery range and increased charging times to coincide, EV charging station owners will see a decrease in their revenue. This is due to fewer customers being able to access the chargers because of longer charge times. To prepare for this situation, the number of Level 3 commercial charging stations should be greater in areas prone to very cold temperatures.

The difference in charge time during extreme cold conditions is a few minutes for a Level 3 charger and several hours for Level 1 and Level 2 chargers.

11. Grid Support

Bidirectional EV chargers can support the grid during overfrequency, underfrequency, and low voltage events. These events are more likely to occur as the number of distributed renewable energy resources continues to expand. Level 2 chargers are ideal for grid support because EVs tend to be connected to them for longer periods of time. Level 2 chargers can be programmed to transition between charge mode, standby mode, and grid support mode depending on grid conditions.

When grid frequency is between 59.98 hertz and 60.02 hertz, Level 2 chargers will operate in the normal mode, either charge or standby, depending on the battery's charge level and predetermined settings. When frequency is between 59.92 hertz and 59.98 hertz, Level 2 chargers will transition to or remain in standby mode. When frequency rises above 60.02 hertz, Level 2 chargers will recognize overfrequency on the grid, and transition to charge mode regardless of normal settings. This is a method of supporting the grid by removing excess energy when it is available.

On the other hand, when frequency is below 59.92 hertz, Level 2 chargers recognize an underfrequency event, and will transition to the grid support mode. The EV battery will discharge its stored energy to the grid until the charge drops to 50% of capacity, when grid support mode will end and the battery will transition to standby mode, even if the underfrequency event persists. In most cases of underfrequency events, additional energy sources can be brought online within 10 minutes, meaning EV batteries would provide critical support for only about 10 minutes, preventing a cascading depression in energy that could lead to a wide area blackout. Using EVs to support the electric energy grid can eliminate the standby energy costs that electric utilities refer to as spinning reserve.

Though rare, a wide area undervoltage event could have costly consequences, including a wide area blackout in a major metropolitan area or even across state lines. The Washington, D.C., Area Low-Voltage Disturbance, which occurred on April 7, 2015, is an example of a disturbance that would have been worse had it occurred in August when air conditioning load is at its peak. If light rail parking lots within the Washington, D.C., metropolitan area were equipped with Level 2 smart chargers that were connected to EVs at the time of this event, recovery from this low voltage disturbance would have been assured.

Grid support mode should also be a feature of residential Level 2 chargers. EV owners who keep their vehicles connected to the charger anytime they are at home could provide the grid with essential energy during grid disturbances.

12. Encourage Consumer Participation in EV Grid Support

While grid support mode will not fully drain an EV battery, EV owners may be more willing to participate in a grid support program with incentives. These can apply to both commercial, long-term chargers and residential chargers. One type of incentive is a lottery system that rewards EV owners for their participation.

Table 1 is an example of a grid support lottery monthly awards. In the table, wholesale energy expenditure shows the total amount the electric utility spent on energy for each month. In comparison, the spinning reserve cost savings is the value that is not spent to maintain reserve energy in the event that a large energy production facility trips offline. Half of the spinning reserve cost savings could be allocated to lottery award winners, who will each be awarded a $1,000 cash prize.

Table 1: Grid Support Awards per 100,000 Participants			
Month	**Wholesale Energy Expenditures**	**Spinning Reserve Cost Savings**	**Number of $1,000 Awards**
January	$52,500,000	$3,000,000	1,500
February	$42,000,000	$3,000,000	1,500
March	$42,000,000	$3,000,000	1,500
April	$21,000,000	$2,000,000	1,000
May	$21,000,000	$2,000,000	1,000
June	$31,500,000	$4,000,000	2,000
July	$63,000,000	$5,000,000	2,500
August	$63,000,000	$5,000,000	2,500
September	$31,500,000	$3,000,000	1,500
October	$31,500,000	$3,000,000	1,500
November	$42,000,000	$3,000,000	1,500
December	$42,000,000	$3,000,000	1,500

The number of participants is the number of Level 2 charger owners that enrolled in the grid support program as tracked by the electric utility. This lottery would award monthly $1,000 prizes whether or not grid support was activated because the monthly savings are the result of reduced spinning reserve expenditures.

13. Disaster Recovery Aided by EVs

Electric vehicles provide an opportunity to assist in disaster recovery efforts without relying on fossil fuel-based energy generation. EVs provide emissions-free electric energy during outages by acting as mobile energy sources, providing electric energy where it is most needed. EVs also provide emissions-free transportation to emergency recovery workers and supplies. This is critical to creating disaster recovery efforts that do not produce greenhouse gas emissions, which worsen the effects of climate change, including more severe storms and natural disasters. For effective storm recovery, electric utilities must preemptively plan how they will quickly provide temporary EV charging stations during storm recovery.

EVs can serve as temporary energy sources in a similar manner to diesel generators that are often used in recovery efforts today. An EV with a 100 KWH battery can provide power to homes and emergency shelters, providing power for mobile charging stations, refrigeration, and indoor climate control via heaters or fans. Before discharging the battery fully, EVs can be driven to a charging station to recharge. The distance from an emergency shelter to the nearest functioning charging station must be considered when using an EV battery as a mobile energy source. Once temporary charging stations are in place, EV batteries can be discharged to 80% capacity before needing to be recharged, allowing batteries to be used for several hours to several days.

In addition, EVs can be used to transport emergency recovery workers to areas impacted by the disaster. For example, when a major hurricane hits the New Jersey coastline, taking out hundreds of miles of power lines, linemen and their vehicles may be recruited from Chicago to assist in grid recovery efforts. The local electric utility holding companies, in this case Exelon, may dispatch linemen who work for Commonwealth Edison in Chicago to assist their Atlantic City Electric crews in New Jersey. With a fleet of EVs at their disposal, Commonwealth Edison linemen can travel emissions-free to New Jersey. Two stops will be required along the 850-mile trek, but once plenty of Level 3 charging stations are available, the recharge time will not be a concern.

Hundreds of other emergency recovery workers, as well as supplies, will need to travel to the disaster site within hours or days. By using EVs to travel, these recovery workers arrive without the use of fossil fuels. The key is to provide for enroute charging and recovery area charging at the end of each workday.

14. Energy Cost and Recovery

Energy cost recovery should not be an issue as energy costs are closely tied to energy consumption. Consumers are billed for monthly consumption in cents per KWH. Energy producers are paid for energy produced in dollars per MWH on the wholesale market. ($70 per MWH wholesale is equal to $0.07 per KWH retail.)

EV owners with Level 2 chargers who consume 34 KWH to charge their vehicles every other day will see their energy portion of their electric bill increase less than $50 per month.

EV owners who use commercial charging stations should expect to see market based, real time pricing when the cost of energy on the wholesale market exceeds $100 per MWH. At other times, the cost should be less than $0.50 per KWH. Historically, the cost of energy only exceeds $100 per MWH during less than two weeks each year. Occasionally, price spikes occur on consecutive days.

Level 3 chargers should be equipped with cost of energy algorithms that increase prices by $0.10 per KWH every time the cost of energy on the wholesale market increases by $10 per MWH and the cost is between $100 per MWH and $250 per MWH. When the cost of energy on the wholesale market exceeds $250 per MWH, the energy cost should be $4.00 per KWH. Table 2 is an example of a variable cost of energy pricing system.

Table 2: Variable Commercial EV Charge Pricing			
Wholesale Cost of Energy	**EV Cost of Energy**	**EV Charge Cost**	**Cost per 100 KWH**
Less than $70 per MWH	$0.10 per KWH	$0.35 per KWH	$35
$120 per MWH	$0.12 per KWH	$0.37 per KWH	$37
$250 per MWH	$0.25 per KWH	$0.50 per KWH	$50
$500 per MWH	$0.50 per KWH	$0.75 per KWH	$75

Note: EV charge costs include utility infrastructure costs, energy production costs, and Level 3 Charger facility costs.

15. Infrastructure Cost and Recovery

For Level 1 and Level 2 chargers in residences, infrastructure cost recovery will occur through the sale of kilowatt-hours of electricity. The need for new facilities will be minimal so the additional kilowatt hour sales will more than cover the additional transmission and distribution facilities.

For Level 2 chargers in parking lots and Level 3 chargers, infrastructure cost recovery will be problematic as many commercial charging stations will have low utilization factors until EV ownership has expanded. If annual utilization factors are low and the cost of new transmission and distribution facilities is high, Public Service Commissions and other rate making agencies will need to allow other ratepayers to subsidize the cost of infrastructure needed to transfer energy to commercial charging stations.

16. EV Charger Maintenance

Commercial charger availability is a major concern of EV owners today, and a factor preventing many potential EV owners from purchasing an EV. Maintaining EV chargers at commercial charging stations needs to become part of electric utilities' daily operations. This will prevent chargers from remaining out of service for extended periods of time and allow them to be available whenever EV owners need to recharge their vehicle batteries.

During preparation of this whitepaper, I made it a practice to monitor the status of the four Level 3 chargers that are near my home. During my first visit, two of four Level 3 chargers were out of service for maintenance. During my follow up visit two weeks later, one of these Level 3 chargers was still out of service for maintenance. It appeared to be a routine occurrence because the owner taped red laminated "out of service for maintenance" notices over the control panel. The length of time that these chargers were out of service is very concerning.

Reliability criteria must be established that enable customers to assess robustness of EV charger maintenance. Two reliability metrics that can be established are:

CAMD – Charger Average Maintenance Duration

CAMF – Charger Average Maintenance Frequency

Nationwide and location specific values must be publicly available online.

17. Catching Up with the Petroleum Industry

As electric vehicle ownership expands, consumers will expect that EVs will be as convenient as internal combustion engine vehicles. Consumers will anticipate that charging stations will be available with similar ease as today's gas stations, the time to charge an EV battery will be short, and the cost will be reasonable. Electric utilities, providers of the electric energy that fuels EVs, will need to match the performance of the petroleum industry. It's likely that electric utilities will bear the brunt of consumer distaste if EV charging does not meet consumer expectations.

Some consumer expectations are unrealistic with current technology, for example, charging a battery as quickly as filling a gas tank. Other consumer expectations are easily met with current technology, such as building charging stations in neighborhoods. New commercial charging stations should primarily consist of Level 3 chargers so that the time to charge is reasonably close to the time to refuel a gas tank.

Table 3 is a brief tabulation of consumer expectations that the petroleum industry provides, and that electric utilities and their partners will be expected to match.

Table 3: Consumer Expectation Comparison

	Petroleum Industry	Electric Utility Partners
Location	Along interstate highways, local highways, and in neighborhood shopping areas.	Along interstate highways, local highways, in neighborhood shopping areas, at homes and businesses.
Cost	$ per gallon ($40 for 10 gallons)	₵ per Kilowatt-hour (KWH) ($30 for 100 KWH)
Wait Time	2 minutes per 10 gallons (400 miles at 40 miles per gallon)	30 minutes per 100 KWH* (300 miles at 3 miles per KWH)
Grade	Regular / Premium	Not Applicable
Refill	At ¼ tank	At ¼ charge
Reservations	Not required	Highly recommended

*Contingent on new charging stations implementing Level 3 chargers.

One significant difference between the petroleum industry and the electric utility industry is that the petroleum industry can transport and store thousands of gallons of gasoline to gas stations. The electric utility industry, on the other hand, relies on "just-in-time" delivery of electric energy. This is an important factor for electric utilities to consider when constructing new charging stations. Renewable energy sources make "just-in-time" energy availability even more variable.

18. Prepare for EVs with Prescient

Electric vehicles will present both challenges and opportunities for electric utilities. By working with Prescient's team of experts, electric utilities can leverage Prescient's analysis and quickly advance their knowledge base of important considerations. Prescient's EV preparedness analysis evaluates current grid infrastructure to determine necessary improvements to support all types of commercial charging stations: neighborhood or highway charging stations, long-haul truck charging stations, and fleet charging centers. Prescient's team models current power system dynamics compared to predicted dynamics with widespread EV usage, including important but often overlooked factors like ambient temperature, congestion analysis, and storm recovery analysis. Prescient's technical reports outline how EVs can be used within the electric utility's service area to stabilize the grid, act as spinning reserve, and serve as backup power sources during neighborhood blackouts.

Prescient has an in depth understanding of electric utility perspectives, consumer expectations, travelers' needs, and battery chemistry. Our team understands utility economics, electric rate structures, energy production costs, and renewable energy availability. Prescient has investigated looming issues associated with EVs, such as battery charge issues in cold weather conditions, mismatches in renewable energy production and EV charging times, and availability of EV chargers when traveling. With insights from Prescient, electric utilities can prepare now for a future with widespread adoption of electric vehicles.

19. About the Authors

Tony Sleva is a seasoned engineering manager, electrical engineer, project manager, and a thought leader in next-generation power system concepts. His contributions extend beyond leadership, encompassing roles as a continuing education instructor, training program developer, forensic investigator, author, and research engineer. At Prescient Transmission Systems, Tony spearheads the development of innovative services and technologies, focusing on areas such as wildfire risk assessment, power outage prevention, and broader advancements in power system engineering.

Alyssa Sleva-Horine is the lead technical editor and business manager for Prescient Transmission Systems. She is an advocate for climate-friendly, next generation solutions for the electric energy grid.

Prescient Transmission Systems provides consulting services for electric utilities in a variety of areas, including electric vehicle integration, physical security, wildfire risk reduction, renewable energy integration, system modeling, and energy balancing. Our focus is on making improvements to the grid using today's data collection technology more effectively.

As subject matter experts, our staff has assessed equipment failures for electric utilities, energy producers, insurers, and large industrial customers. We are passionate about sharing our vision of the next generation electric energy grid. We see change as an opportunity as we prepare for a future with climate change.