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The Need for a Smart Charging Infrastructure

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Abstract

Climate change, security issues of importing oil and a lack of control over petroleum-based fuel prices are three key issues prompting auto makers to develop Battery Electric Vehicles (BEVs) and Plug-in Hybrid Electric Vehicles (PHEVs). Electricity offers a number of benefits over petroleum-based fuels: It is produced locally, it is more efficiently converted to kinetic energy, and it can be generated from clean and renewable energy sources. According to an Electric Power Research Institute (EPRI) study, the adoption of PHEVs is expected to reduce cumulative greenhouse gas emissions by a total of 3.4-10.3 billion metric tons by 2050. Due to the many benefits, major automakers will announce mainstream BEVs and PHEVs over the next two years.

Yet to enable the adoption of electric vehicles, drivers need access to convenient methods of charging them. Garage charging is inadequate; for example in the US, there are only 54 million private garages for 244 million cars. Electric vehicles must be plugged into the grid for recharging, but there is currently a lack of infrastructure to provide this charging service in convenient locations, such as parking lots, curbside and in public garage parking stalls. Moreover, providing simple outlets in public areas is problematic. Without control, usage, safety and liability issues arise, and there is a potential for electric grid inefficiency and overload. Moreover, there is no way to generate revenue for energy and maintenance.

In this paper, 365 Energy AG president Pierre Clasquin and Coulomb Technologies founder and CEO Richard Lowenthal discuss the need for creating a smart charging infrastructure for electric vehicles and how the convergence of networking technology and energy management technology brings value to drivers and station owners. They also explain the required components of a smart public charging infrastructure, as well as key features and capabilities that will make it a viable solution for owners of electric vehicles, charging station hosts and utility companies.

Keywords: charger, charging, EV (electric vehicle), infrastructure, smart grid

1 Introduction

Plug-in Electric Vehicles are the next step in the evolution that brought us hybrid cars, with the potential to radically alter dependency on petroleum for transportation and provide a path to substantially reducing greenhouse gas emissions. A recent Electric Power Research Institute (EPRI) study calculates that the plug-in vehicles to be introduced in 2010 will save between 1.2 and 3 metric tons of CO2 per year per vehicle, compared to conventional gasoline-powered vehicles [1]. According to the same study, by 2050, with moderate market penetration of plug-in vehicles, an estimated aggregate savings of 400 million metric tons of CO2 per year is possible.

In light of these predictions, we are less than two years away from the revolution in automobile transportation.

Figure 1 captures the new plug-in vehicle sales that are to be expected in the next few years based on a Morgan Stanley March 2008 report [2].

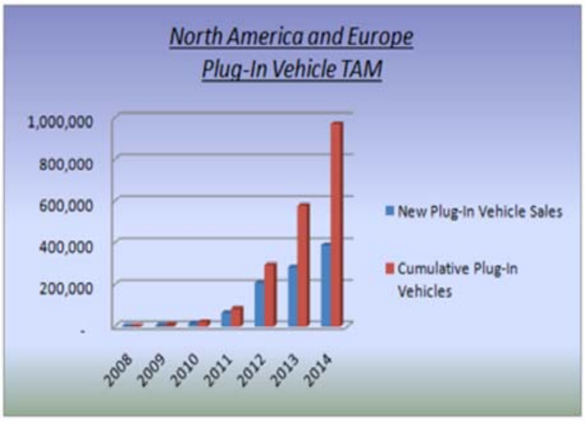

Figure 1: New Plug-In Vehicle Sales in U.S. (Total Addressable Market)

1.1 Why Plug-in?

There are many benefits to plug-in vehicles that are driving the trend in the automotive industry toward developing vehicles that run on electricity.

Reduced fuel cost to consumer

The most salient benefit to consumers of driving a plug-in car is reduced fuel expense. Using the Chevy Volt as an example, once charged, the car uses only electricity for the first 40 miles, running off batteries. After 40 miles, a small gasoline powered generator in the car will sustain the battery, extending the range to over 300 miles. Since the average person drives fewer than 30 miles per day, most owners of these cars can avoid going to the gas station entirely. This is an attractive proposition financially, considering the cost of driving on household electricity is about 2 cents per mile whereas the cost of driving a typical Internal Combustion Engine (ICE) car is 13 cents per mile at a $3 per gallon gas price.

Whereas hybrids offer efficiency in the 40 miles per gallon range, plug-in cars are expected to deliver 100-150 miles per gallon and even all-electric operation.

Reduced oil dependency

In addition to financial benefits to consumers, the introduction of plug-in cars has the potential to radically alter dependency on petroleum for transportation and to substantially reduce emissions of greenhouse gases.

Reduced environmental impact

In California, transportation accounts for almost 40% of the GHG Emissions, renewable energy sources are growing exponentially and the state has goals of achieving 20% of electricity mix through renewable sources by 2010, the potential savings becomes very significant {Figures 2 and 3}.

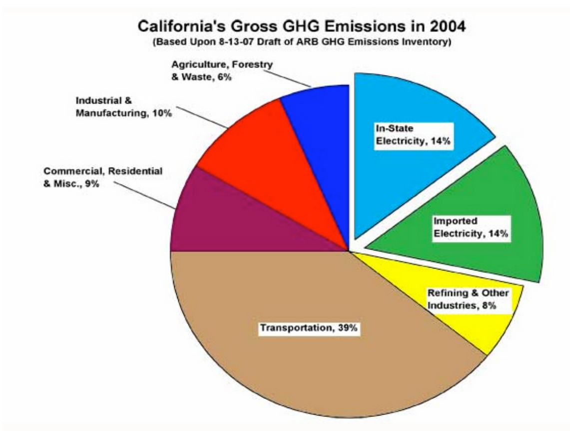

Figure 2. California's Gross GHG Emissions and Renewable Power Capacity

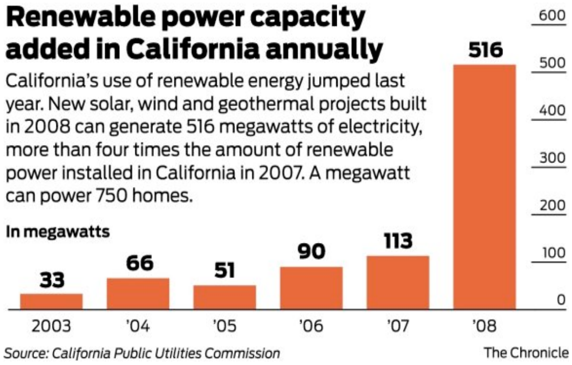

Figure 3: Renewable Power Capacity in California.

The clear benefits of plug-in vehicles will continue to prompt consumers and automakers toward this trend resulting in major growth, but the real enabler will be an efficient, convenient and financially viable method for charging the vehicles.

[Note:]

Electricity is measured in kilowatt hours (kWh). The distance a vehicle can travel on a kilowatt hour depends on several factors, including weight, battery efficiency and driving habits. The Tesla Roadster has an EPA estimated range of 220 miles on a 53kWh battery pack, and the Chevy Volt is estimated to go 40 miles on 8kWh of battery. A typical electric utility charges for electricity at $.09 per kWh. Using Tesla's EPA estimates, the cost of going one mile on electricity is just $0.0217 (53 x $.09 / 220).

2 Challenges of Creating a Charging Infrastructure

To create a viable solution for drivers of PHEVs, three challenges must be addressed:

1. Where will people charge their vehicles?
2. How will the recurring costs, including the cost of electricity, be paid?
3. How will grid load be managed?

2.1 Where Will People Recharge?

PHEVs and BEVs are designed such that they can be plugged into a home garage at night for fuelling. Unfortunately, 40 percent of U.S. residences don't have even a carport, much less a garage, in which a plug-in vehicle can recharge overnight. Research shows, there are 244 million cars [3] in the U.S. today and only 54 million garages [4]. Garages are most frequently lacking in dense urban areas, the very places where a medium-range electric vehicle is an ideal solution for personal transportation. For example, in San Francisco only one in six cars are parked in private garages. In suburban areas, people living in apartment complexes and condominiums also need a place to "plug in."

In addition to the lack of garage access, the limited electricity-only range of early plug-in vehicles will prompt the desire for drivers to "top off" their batteries when away from their normal overnight charging location.

Electric vehicles must be plugged into the grid to refuel, but a public infrastructure to provide this service does not yet exist. Prospective plug-in car owners want the assurance that they can charge their vehicles at home, while at work, or parked anywhere for extended periods. Recent studies of drivers of early electric vehicles confirm this behaviour. A University of California at Davis study showed that 80% of plug-in vehicle owners wish to charge more than once a day. With only 54 million private garages, we only have 12% of the charging stations we need {Figure 3}.

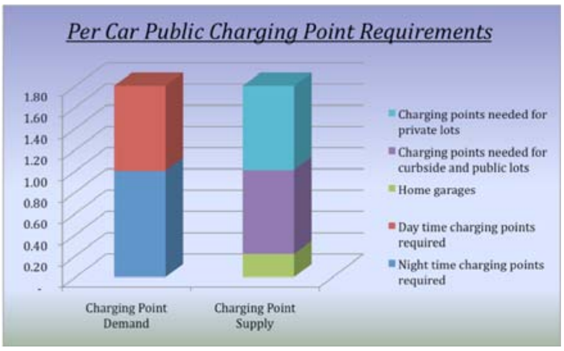

Figure 3: Charge Point Requirements per Vehicle

The bar chart above summarizes the charging point demand for a single average car as a function of time of day and location. The gap between supply of existing charging points and the demand is large and clearly points to the need for a plug-in vehicle-charging infrastructure.

To be successful, such an infrastructure must have the flexibility to manage a wide range of existing requirements as well as adapt to not-yet-developed taxation options and evolving customer expectations.

On average, cars are parked roughly 23 hours per day in home garages, apartments, condominiums and hotel garages, employee parking locations, public lots and curbside. To meet driver demand for convenient charging, these are the locations in which charging stations should be installed.

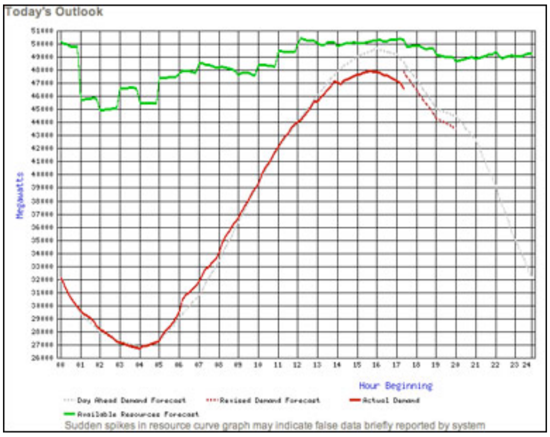

Figure 4: Typical Grid Load Profile

2.2 Who Will Foot the Bill?

Providing simple outlets in public areas is fraught with problems, including safety and liability issues, energy theft and cord theft. Without management, the potential for electric grid inefficiency and overload can pose significant problems for consumers and utility companies. Other concerns include a lack of a revenue source to pay for energy and maintenance, a lack of an incentive to purchase stations, and the high cost of monitoring and maintenance.

The charging infrastructure must give drivers the ability to pay for charging services and the use of stations through a fee that covers the cost of electricity, maintenance and the capital costs of the infrastructure itself. The charging stations should also provide municipalities the ability to collect transportation taxes once they are imposed on electricity as a fuel, as they are today on gasoline.

2.3 How Will the Grid Be Managed?

Utilities are concerned about grid expansion and the costs associated with it. The grid is designed for peak capacity and peak demand occurs typically between noon and 6 p.m. in the hot summer months. Figure 4 depicts the grid load valley times (a.k.a. low demand) and peak times (a.k.a. high demand).

A charging infrastructure should be able to maximize charging during valley times and minimize charging during peak times and be able to shed grid loads (a.k.a. "peak shaving") during times when the grid load becomes an issue.

3 The Network as the Enabler

A networked charging infrastructure will provide numerous benefits to all stakeholders, including subscribers, hosts and utilities. In fact, it is a necessary enabler for the widespread adoption of electric vehicles.

Through a networked platform, new policies and features can be easily implemented. A network infrastructure also offers the benefit of remote software upgradability, so that no truck rolls are required to add new features. This future-proofs the solution. Networking capabilities can also help taxing authorities recover revenue lost when gasoline taxes diminish due to a shift away from gasoline and diesel toward electricity as transportation fuel.

Let's take a look at how a networked charging infrastructure can benefit subscribers, hosts and utility companies.

- ***Subscribers.*** A networked charging infrastructure can offer mobility and ubiquity to EV drivers, since they can charge their vehicles at any public charging station, regardless of which host owns the station or which utility supplies the electricity to the station. All of the payment distribution is handled on the backend, transparent to the user. Access to networked stations can be provided to drivers via Google Maps or another locator service. Strong standards-based encryption can be employed to secure communication across the network and protect subscriber IT and payment data.

A viable network solution will provide enough flexibility in payment plans to accommodate different drivers—everything from a pay-as-you-go model to unlimited usage plans. Software upgradability can enable the deployment of new features as they become available, such as new forms of authorization and payment like RFID-based credit card systems or gift cards, making charging even more convenient for subscribers. Built-in redundancy of a wireless mesh networking technology creates a highly reliable infrastructure.

- ***Host.*** For the actual owner of the networked charging station, or host, the network infrastructure can enable new business models. Hosts can collect payback for electricity usage as well as station operations and maintenance. Subscription fees will even cover capital costs for the stations themselves. As a result, the station becomes an investment with potential revenue streams. Hosts can also use charging stations as differentiators, making them available to drivers as a free service, for example, or as a benefit to an employee or tenant.

  With smart functionality embedded in the stations, the electricity outlet in the station is activated only when an authorized subscriber plugs in. Safety mechanisms such as GFCI can be implemented such that they can be reset from the network.

  Advanced troubleshooting and monitoring capabilities such as diagnostic and monitoring tools can be added to help the host identify a potential issue before it ever affects charging service. Detailed occupancy information can be collected by the network and made available to the host for each of the charging stations, allowing the host to determine which locations are most in demand, or where further investment in additional charging stations would be worthwhile.

- ***Utility.*** For the utility company, a networked charging infrastructure addresses the problems of time and location based predictability of grid load. Network operation and subscription pricing offers a way for utility companies to shed plug-in vehicle loads during peak and upper peak generation time periods at any level, from an entire service area down to a single charging station. Metering capabilities within stations can track usage with a high degree of accuracy, giving utility companies more control and visibility.

4 Components of the Networked Charging Infrastructure

Within the networked charging infrastructure will be the following components:

1. Smart charging stations
2. Network operating system
3. The communication network
4. Network and policy administration server
5. Network Operations Centers (NOC)
6. Remote Payment System (RPS)

4.1 “Smart” Charging Stations

The idea behind a “smart” charging station is the ability to embed intelligence in the appliance, with network connectivity to the administration server that supports advanced capabilities.

The charging stations themselves must be rugged and attractive for installation in conspicuous city locations. These stations will be ground-, pole- or wall- mounted to provide installation flexibility.

Smart charging stations can provide an authorization interface for a key fob or smart card for energy authorization. Bi-directional energy metering can be implemented to track usage and provide flow management. The charging station should offer the ability to perform remote diagnosis and Ground Fault Interrupter resets, and security features should include cord locking. The networking interface will include 802.15.4

wireless LAN technology with optional GPRS and GSM technology.

Many of the smart features in the charging stations can be implemented directly and locally in the station itself. The more sophisticated features, including user authorization, rate optimization and utility-based load management require an IT infrastructure and a communication network to facilitate communication between the NOC management application and the charging station.

4.2 Network Operating System

Each local group of networked charging stations connects to a Network Operating System (NOS) through a gateway. The gateway can be an enhanced charging station that contains a GSM cellular modem. The NOS will run on a remote administration server at the NOC, and supports multiple web-based portals for access to reporting, billing and usage information that comes from the charging stations.

4.3 Communication Network

The network should provide options for both local and wide area connectivity and communication. For the local connection, a meshed wireless LAN environment is sufficient. For wider connectivity and communications back to centralized servers at the NOCs, CDMA and GPRS are typically used. Over this network, the NOC can communicate with and individually control the charging stations to provide authentication, management and real-time control.

4.4 Network Energy and Policy Administration Server

A centralized control system communicates to all stations in order to implement energy administration policies, perform billing and reporting functions, and send information to navigation systems for real-time updates on available stations. All stakeholders, including utilities, consumers, corporations and municipalities should have access to this server.

4.5 Network Operations Center

Through the networking interface, the abilities of the station are dramatically enhanced by software and data at a remotely located NOC, where the network energy and policy administration server resides.

4.6 Remote Payment System (RPS)

An RPS can be implemented for users who are not subscribers but may wish to use the charging station or parking meter functionality using a credit card. This capability adds revenue potential for the host and utility companies, and provides convenient charging for non-subscribers.

4.7 A Typical Network Configuration

Now we will look at a typical network configuration of charging stations using this model.

In a given area, a cluster of networked charging stations can communicate with each other over the 802.15.4 wireless radio network. One charging station within the cluster acts as the gateway, using a CDMA or GPRS modem to communicate back to a central network policy and administration server. Here, all of the subscriber policies, energy management policies, accounting, billing and reporting are accomplished. subscribers, hosts, utility companies and fleet managers can provision, view and manage the stations through web-based portals provided through the server.

Figure 5 and 6 show two views of networked charging infrastructure components and how they work together.

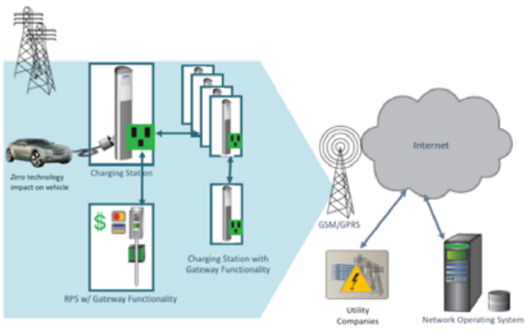

Figure 5: Networked Charging Infrastructure

Figure 6: Networked Charging Infrastructure

4.8 Key Features and Functionality

The following features should be implemented in the networked charging infrastructure to enable the functionality, flexibility, security and availability necessary to provide acceptable service levels to drivers.

- GFCI ground-fault protection circuitry for user safety
- Bi-directional, utility-grade power management to enable metering circuitry and provide accurate measurement of energy delivered for charging
- Standards-compliant wireless mesh networking (802.15.4 radio)
- 128-bit AES encryption to optimal security
- Cord security using locking doors on charging stations to prevent theft
- Integrated RFID reader to identify key fobs
- Integrated parking meter functionality to provide a direct replacement function for existing parking meters
- Bright and easy to read display
- Remote firmware upgrades over the network
- Remote management for authorized operators over a web interface
- The ability for the station to go into power-saving mode between charging to save energy
- Operational alerts transmitted over the network to authorized operators

5 Benefits of a Smart Public Charging Network

A client-server network such as the one described in the previous section provides a simple, yet feature-rich experience to subscribers, hosts and utility companies. Using this model, the networked charging infrastructure:

- Enables a financial flow in which drivers pay for the value they get when they charge, as well as a premium to cover maintenance and capital costs that hosts would normally absorb.
- Allows charging stations to be monitored and maintained remotely from a data center, reducing service calls.
- Delivers advanced features like interaction with the electric grid helps to optimize energy use.
- Improves security for drivers and hosts with RFID authentication, and enables utility companies to accurately track and bill for usage.
- Gives subscribers more flexibility and mobility, since they can plug in wherever there is a charging station on the network.
- Adds value for drivers and increases usage with integration with navigation systems and Google maps.
- Enables greater public safety and reduced liability, because the charging stations can be de-energized until the user authenticates and plugs in.
- Allows for the implementation of electric grid friendly programs, leading to lower cost of energy from utilities.
- Allows for automatic reconfiguration through the network, eliminating truck rolls and providing faster user access to new features.

All of these features help to minimize service and maintenance costs while providing maximum ease of use and flexibility and rich functionality to all stakeholders.

6 Conclusion

A smart public charging network provides all the critical features for enabling the EV revolution. Networking enables a financial flow whereby drivers pay for the value they get when they charge their vehicles, along with a premium for covering the cost of maintenance and capital. This model also provides income to charging station owners. Networking allows charging stations to be monitored and maintained remotely from a centralized server that can deliver advanced features, such as interaction with the electric grid to optimize energy usage and load balancing to relieve potential grid overload. It can also make navigation data available to help drivers find available stations.

By combining networking intelligence with smart charging stations, the smart public charging network delivers the features and functionality for the new generation of PHEV and BEV drivers, providing incentive and momentum for the adoption of electricity as a fuel for vehicles.

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