Electric Vehicles and the Smart Grid

MAE 188

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Abstract

This research paper deals with the integration of electric vehicles into the Smart Grid. With gas prices near all-time high, electric vehicles are poised to enter the mass market in the United States. Our current Smart Grid system already experiences overloads during peak hours. A huge strain would be put on the grid if a large amounts of electric vehicles all charge during peak hours. This can result in causing electricity transformers to combust, which can result in blackouts for thousands of companies and homes (Jones, 2012). The goal of this paper is to figure out a method to prevent electric vehicles from overloading the Smart Grid. During the research, key information were found about key technologies and standards of electric vehicles, Smart Grid peak levels, electric vehicle charging pricing strategies, and existing/future approaches to our problem. To prevent electric vehicles from overloading the Smart Grid, it was concluded that we had to better manage the electric vehicles electric energy consumption and the health of the Smart Grid through the installations of charging terminal, communication devices, and Smart Grid management programs. The pros and cons of our plan were discussed and it was discovered that our pros outweighed the cons. The main problem preventing our scenario from becoming a reality is the cost of the integration, something that not many investors are willingly to invest in.

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Introduction

An electric car is a car that is powered by an electric motor instead of a gasoline engine. It is a much more fuel efficient and environmentally friendly transportation method compared to gasoline cars. Figure 1 compares electric vehicles and gasoline powered vehicles (Electric, 2012).

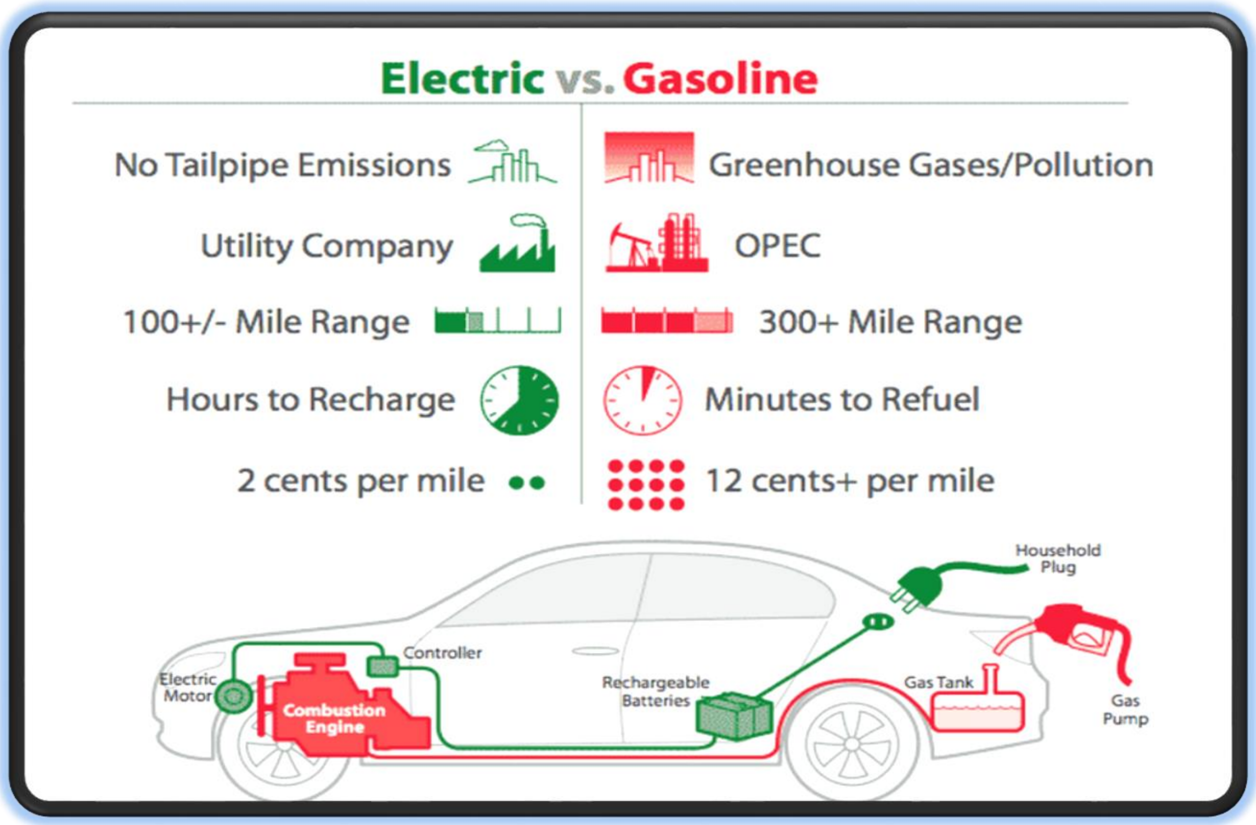


Figure 1: EV vs. Gasoline

Although historically, electric vehicles has not been widely adopted for its limited driving range before needing to be recharged and its long recharging times, its popularity have increased over the past few years. There are many different types of electric vehicles on sale in the market like the Nissan Leaf, Ford Focus, and Chevy Volt. It is estimated that electric vehicles sales will increase from 114,000 vehicles in 2011 to 5.2 million vehicles by 2017 (Stephanie, 2012). As gasoline prices continue to increase to all-time highs and governments giving incentives like $7,500 tax credit for the purchase of an electric vehicle (Thompson, 2012), the consumers' interest in electric vehicles will continue to increase as well. Figure 2 project the estimated electric vehicle market size through 2015 (Gadh, 2012). This paper will discuss the effects of electric vehicles on the Smart Grid and how electric vehicles can be effectively implemented into the Smart Grid.

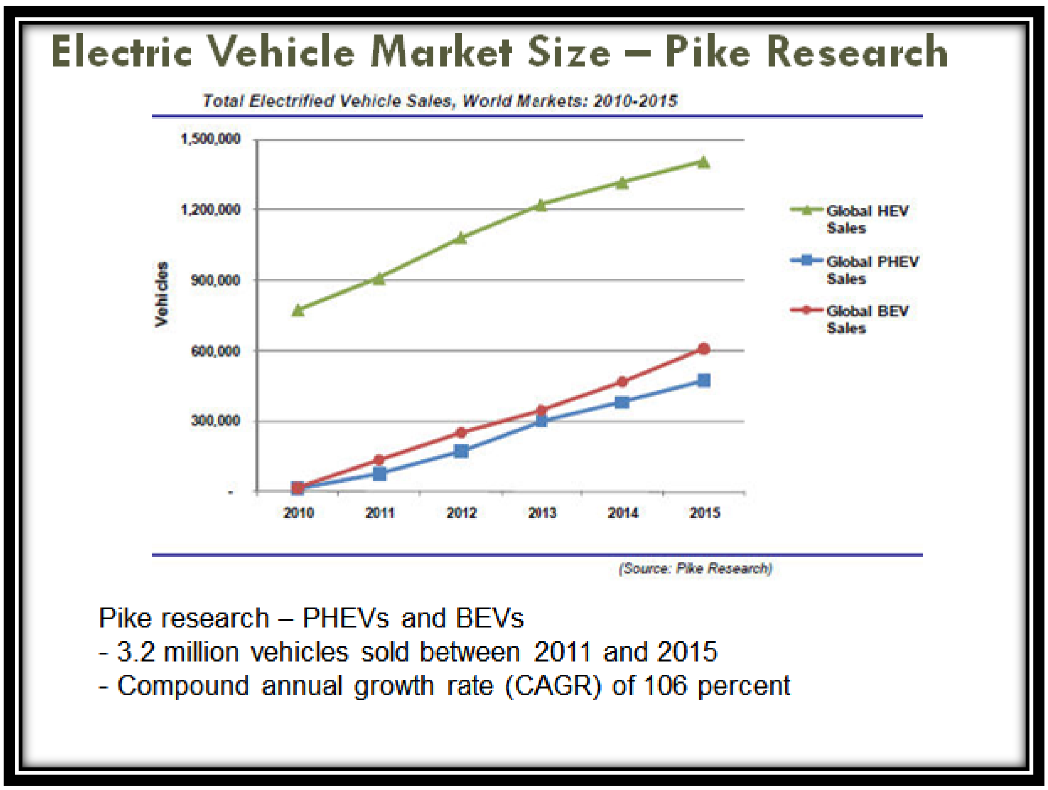


Figure 2: Electric Vehicle Market

The Smart Grid is the digital technology that allows for two-way communication between the utility and its customers. The Smart Grid consist of controls, computers, and automation all working together with the electrical grid to respond digitally to the ever changing electric demand (Grid, 2012). The Smart Grid allows more efficient transmission of electricity, faster restoration of electricity after power disturbances, and reduced operations costs for utilities and lower power costs for consumers.

The main focus of this research paper is to research and discover different ways to create an effective infrastructure where electric vehicles can effectively work with the Smart Grid. In order for an effective infrastructure to be built, we must consider the pros and cons of electric vehicles and the cost that it will have on the consumers. It is irresponsible to pour investments into an infrastructure for a product that may not be able to gain a good market velocity; while on the other hand, a lack of infrastructure is the reason why electric vehicles are not able to penetrate into the marketplace.

Currently our Smart Grid system may not be able to handle a massive increase in electric load, especially during peak hours. The reliability of the grid is dictated by generation capacity, storage, and demand. During certain peak hours, our Smart Grids are already overloaded. If the number of electric vehicles were greatly increased on the road, our Smart Grid system might not be able to handle the increase in energy usage (Bellard, 2012). In order to prevent our Smart Grid system from overloading, we must implement electricity usage monitoring software, improvements in the electric vehicles' batteries, and better electric pricing methods. Electric vehicles do not have to become a problem to the Smart Grid, but it can be helpful to the Smart Grid.

Describing the Project

This research project involves researching into electric vehicles and the Smart Grid. The goal of this research project is to discover ways in which electric vehicles can be implemented with the Smart Grid. If the number of electric vehicles increases dramatically and they all charge at the same time, the Smart Grid will be overloaded. Figure 3 shows the Smart Grid peak values if certain amount of cars is charging during a certain time period.

The purpose of this project is to figure out methods to prevent electric vehicles from overloading the Smart Grid. Some of these methods include better and updated infrastructure for electric vehicles, improvements into electric vehicle batteries, and electricity data monitoring programs.

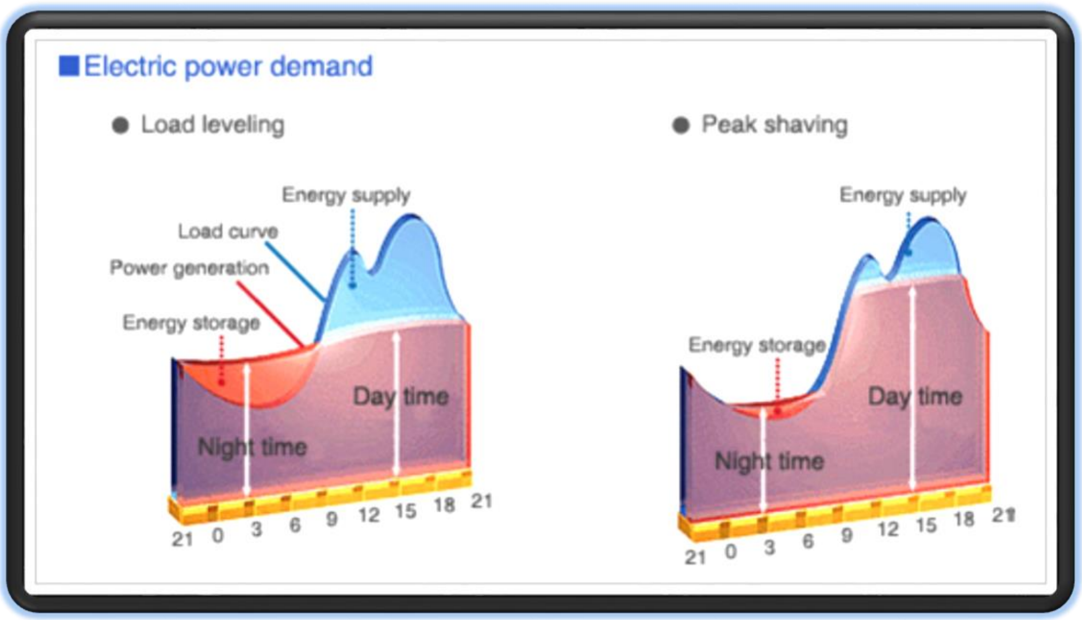


Figure 3: Peak Values

In order to accomplish our goals, we will research into many different areas such as: key technologies that are relevant to the domain of our project, existing methods and approaches that are used in our problem domain, existing standards that are used for electric vehicles and its infrastructures, the type of information and data that is transmitted between the Smart Grid and electric vehicles, and the cost and benefit considerations of implementing electric vehicle to the Smart Grid.

When enough research has been done, we will create a scenario in which our project can be potentially implemented and discover the pros/cons of our approach. We will compare our scenario with existing methods and approaches and figure out any weaknesses between them. With the research we have done, we will be able to discuss the future of electric vehicles and the Smart Grid.

Key Technologies

Some of the key technologies that are relevant in helping electric vehicles work with the Smart Grid are DC to AC converters, electric vehicle battery, grid interconnection (grid to vehicle and vehicle to grid), power source, Smart Grid security, and an improvement in the overall infrastructure.

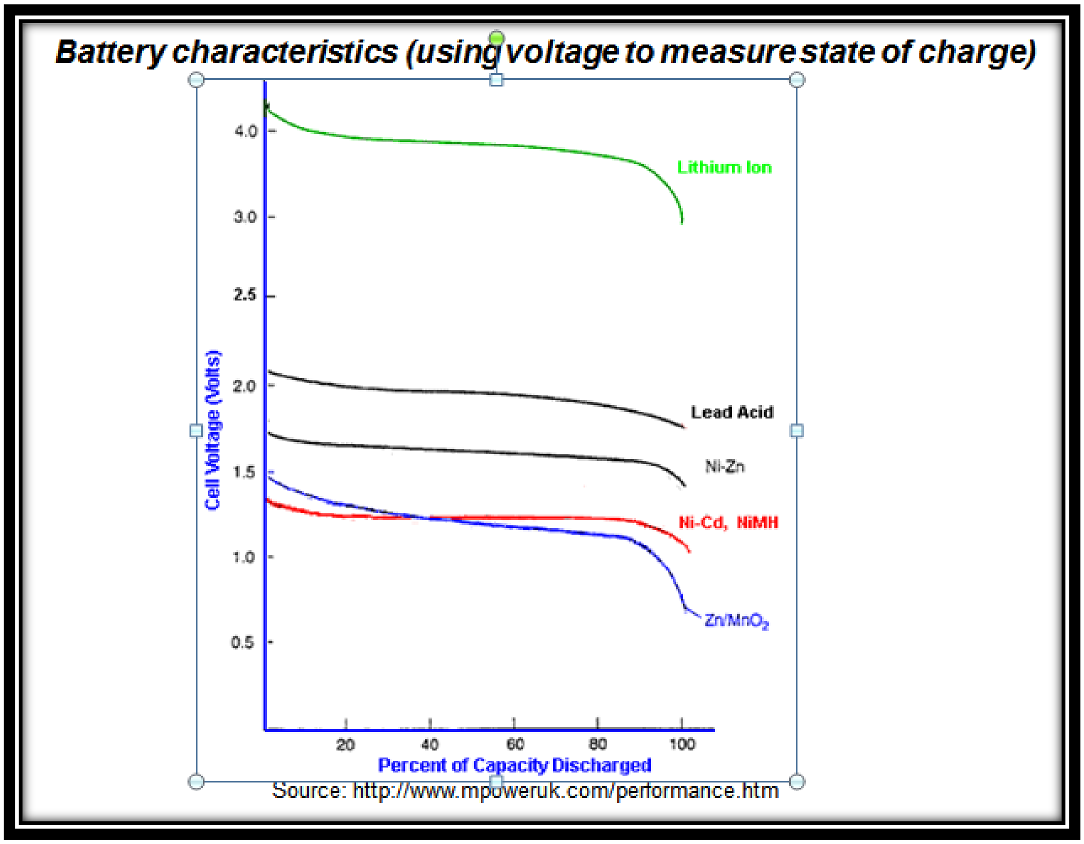


Figure 4: Cell Voltage

Electric car batteries or traction batteries are rechargeable batteries that are different than starting, lighting, and ignition (SLI) batteries because they are designed to give power over sustained periods of time. The increase in cost of gasoline and the decrease in price of batteries have contributed to an increase in electric vehicle sales. Currently Lithium Ion is the preferred type of material that electric vehicle's batteries are made of because Lithium is considered the most effective material for batteries. Figure 4 shows the cell voltage of Lithium compared to other materials (Gadh, 2012). If the cost of batteries can be reduced and the life span of the batteries be increased, the cost of electric vehicles can decrease, promoting more people to purchase them.

If electric vehicles had DC to AC convertors designed included on them, charging the electric vehicles would be less difficult and more convenient. A grid-tie inverter (also known as synchronous inverters) converts DC to AC and feeds the electricity into the existing grid. The grid-tie inverter would allow the battery source be connected to the grid (Gadh, 2012). Some key variables to consider when dealing with the grid-tie inverter are the power supply, voltage, frequency, efficiency level, max input and output currents, and rapid disconnect for safety in case the grid goes out. With the DC to AC convertors and improvements in the design of batteries, electric vehicles can store energy that can possibly be transferred back to the Smart Grid.

To prevent the increase in energy consumption of electric vehicles from draining our power supply, different types of power plans will have to be created that will limit people's charging times and monitor energy consumptions. In order to monitor energy consumptions by electric vehicles, better grid interconnections must be designed so that it can monitor energy and information transfer between charging stations and home. Smartphone apps like the WinSmartEV that is shown in figure 5, will be able to monitor electric charge usage and peak values (Gadh, 2012). High levels of security need to be created so that people's private information is not accessible by other people during the transmission of data between charging stations and the grid.

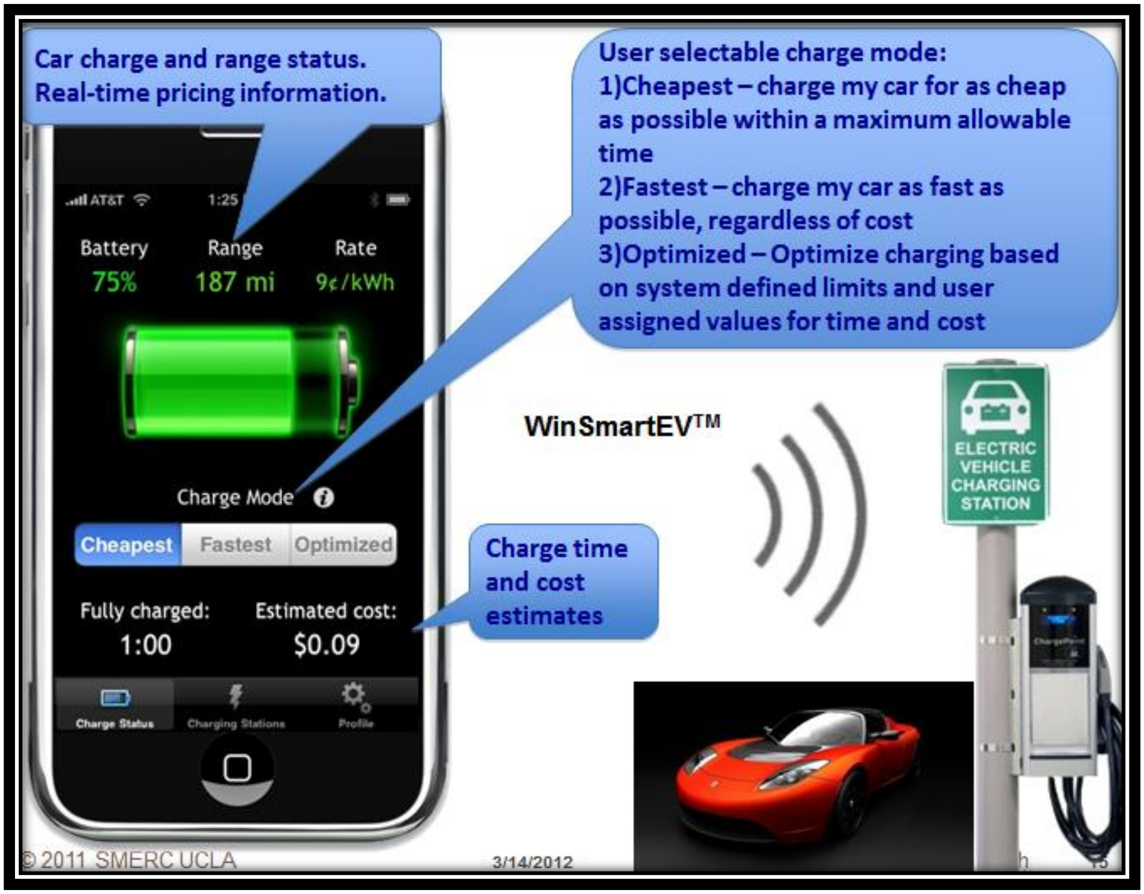


Figure 5: WinSmartEV

For electric vehicles to be convenient for everybody to use, there must be improvements in the infrastructure of electric vehicles. There needs to be more charging stations so it is more convenient for people to charge their cars. Currently there are only around 5000 public charging stations in the United States compared to 116,000 public gasoline stations (Li, 2012). When asked if drivers would pay for a home charging station, 1/3 said no, while another 1/3 said only up to $500 (Electric, 2012). The lack of charging stations makes electric vehicle owners hesitant to travel far distances.

Better data communication needs to be established between charging stations and the grid so that peak overloads do not happen and better pricing strategy can be created. RFID is a wireless program that reads the data from the charging stations and takes it to the control center where it then transfers the data to the grid (Gadh, 2012). Figure 6 shows an image of how RFID works. The RFID will be able to keep track of energy usage and electricity prices.

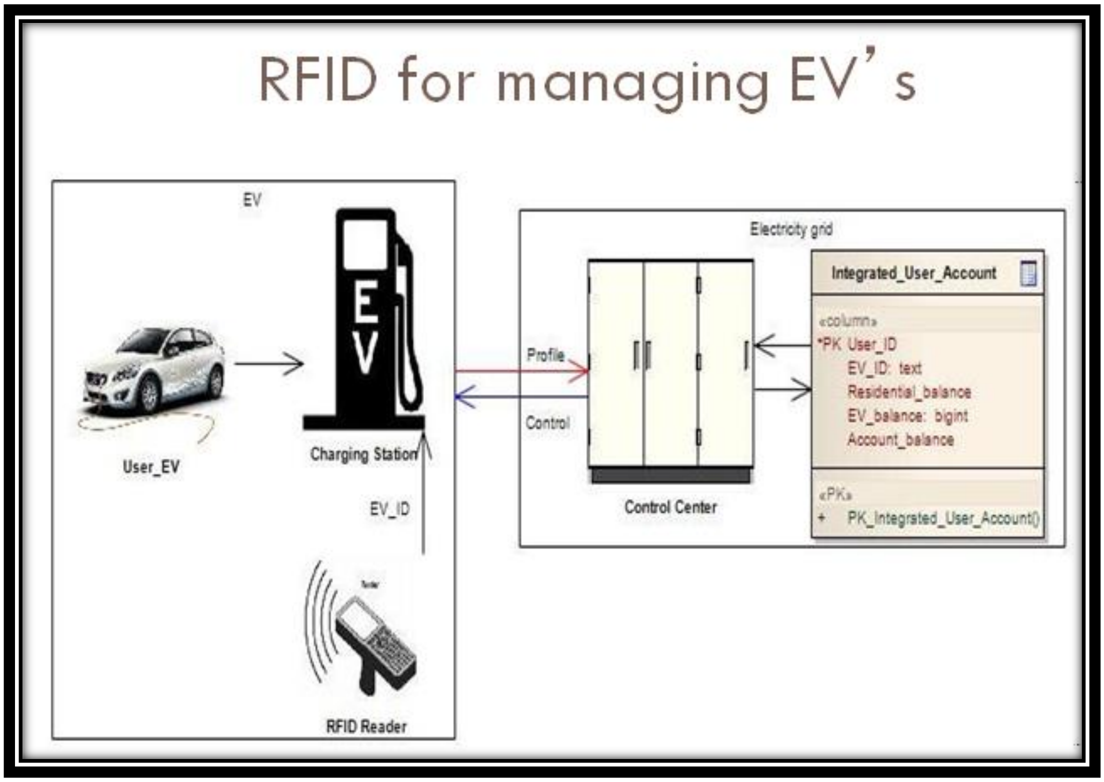


Figure 6: RFID

When making improvements on key technologies or creating new technologies, we must determine if the cost is worth the benefit. These key technologies will determine how successful electric vehicles can be implemented with the Smart Grid.

Existing Methods to Problem

There are many issues with the current operation of electric vehicles with the Smart Grid. The infrastructures today cannot support to charge many electric vehicles effectively or monitor the electric usage/charge rate of the electric vehicles.

Electric cars cannot travel long distances compared to gasoline powered cars because the current batteries used in electric cars cannot store enough energy and there is a lack of charging stations. The battery lives of the electric cars are improving as figure 7 shows the trend in battery energy density over the past few years (Kelly). The battery trend is kind of following Moore's law, however nowhere near the trend of computer chips. The amounts of charging stations on the road are going to increase as President Barack Obama wants to offer $1 billion to 15 United States cities to invest in clean-vehicle infrastructure including charging stations for electric vehicles (Udy, 2012).

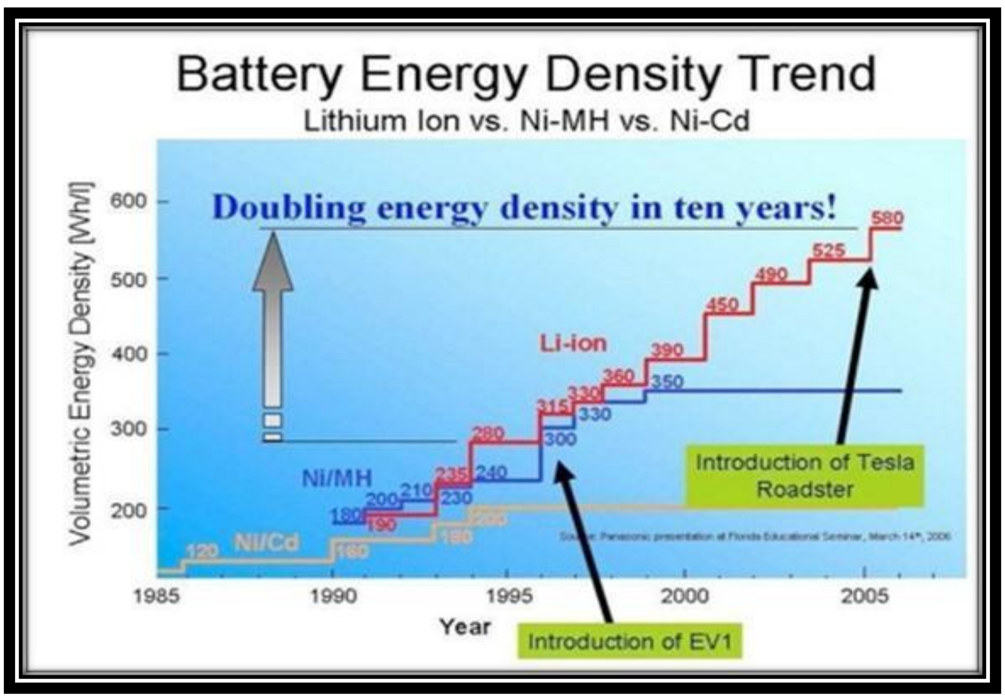


Figure 7: Battery Density

Energy storage is a huge drawback in electric vehicles, but as MIT researchers have mentioned that they are doing research to change this problem as they design “a system (that) would permit the possibility of simply ‘refueling’ the battery by pumping out the liquid slurry (which was charge originally) and pumping in a fresh, fully charged replacement …” as one MIT researcher explained in its article (Chandler, 2011). This allows the possibility of quickly charging EVs in a short amount of time, which is similar to pouring gasoline into cars, while we have the “option of simply recharging the existing material when time permits” as stated later in the MIT article.

A plan needs to be developed to spread the time that electric vehicles are charged. One possible solution is the development of vehicle to grid interface design, where the batteries in the car can store energy and transfers it back to the grid (V2G, 2012). People are afraid that their electric vehicles might be useless if a blackout occurs because all the charging stations would be powerless. On the contrary, people like Dr. Swinney have used his electric car battery as an extra power supply during blackouts (Motavalli, 2007). There is an inverter, which converts the direct current electricity from the batteries to the household current and it regulates the voltages. This type of vehicle to grid technology can bring additional benefit of delivering electricity to help stabilize the grid and reduce demand during peak hours. With improvements in the battery life and grid connection, electric vehicle owners can power their own house during blackouts and sell their energy back to the grid.

Standards

If the numbers of electric vehicles on the road are going to increase, there must be many different standards that need to be accounted for. Some of the standards that need to be regulated are the price of electricity at charging stations, electric car chargers, battery life, and safety regulations.

Although the price of gas can vary at different gas stations, there is still some kind of price standard that the gas stations follow so the price of gas per gallon doesn't vary that much from gas station to gas station. Unlike gas stations, the price of electricity can vary greatly from different stations. Currently, electric charging stations charge customers at a fixed rate, usually higher than the current price of electricity (Nice, 2012). The current price of electricity changes constantly throughout the day, with the highest price during peak hours (Smart). If there is no standard charging prices that is reasonable and affordable for the drivers, people will just charge their electric vehicles at their homes.

Batteries are typically the most expensive part of the electric car. Most existing electric vehicle batteries are 3.3 kilo-watts (Gadh, 2012). The next generations of batteries are expected to be 6.6 kilo-watts. The charging time depends on the power in kilo-watts. Figure 8 shows the comparison of some of the top electric vehicles on the market.

Table 1: EVs

EVs - comparison

Company	Chevrolet	Nissan	CODA	Tesla
Model	VOLT	LEAF	CODA Sedan	Roadster
Picture				
Miles per charge	40	100	90-120	160, 230, or 300
Types of chargers	120/240V	110/120 or 220/240V	220V	110 or 220V
Charging Time	10 hr (120V) or 4hr (240V)	8 hr (220/240V)	6 hr (220V/30A)	4 hr (220V/70A) or 30+ hr (110V/15A)
Top speed (mph)	NA	90	80	120
Reference	http://www.chevrolet.com/volt/	http://www.nissanusa.com/leaf-electric-car/	http://www.codaautomotive.com/	http://www.teslamotors.com/

Universalizing charging equipment in electric vehicles will make electric vehicles more compatible to different charging levels at different charging stations. Currently, each electric vehicle car company makes their own type of charging plug. This idea of every company owning its own charging stations makes expanding electric vehicles difficult because these specialized plugs are only accepted at certain qualified stations. There needs to be universal standard so electric vehicles can be charged at any location. Just like the concept of the USB plug for computers, a universal plug for electric vehicles will make charging much easier and more convenient.

The Society for Automotive Engineers and consortium of Japanese companies are creating standards for charging plugs with their invention of the SAE J1772 plug (New, 2010). A critical milestone was reached in 2010, as the SAE J1772 became the universal standard for charging station connector (Snapp, 2012). This allowed the industry to free market competition to drive better pricing and eliminating the risk of placing the wrong connector on charging stations. The SAE j1772 are 120 or 240 volts and are in 43 mm diameter connector with five pins and 3 different pin sizes (Gadh, 2012).

There are many different types of charging stations such as level 1, 2, and level 3. Table 1 lists the information of the charging time and cost of each charging station. Table 2 lists the details like voltage, current, and power of each charging station (Morrow, 2008). Level 3 chargers are the most expensive, but provide the fastest charging times. Level 3 chargers are usually found in public charging stations. Level 1 chargers are the most commonly used in households. Level 2 chargers are best suited for overnight charging.

Table 2: Charging Stations

Charger Name	Charging Time (HR)	Cost ($)

Level 1	20	900
Level 2	8	2,200
Level 3	1	40,000

Table 3: Charging Stations Info

	Voltage (VAC)	Current (Amps)	Power (kVA)	Freq. (Hz)	Phase	Standard Outlet
Level 1	**120**	**12**	**1.44**	**60**	**single**	**NEMA 5-15R**
Level 2	**208/240**	**32**	**6.7/7.7**	**60**	**single**	**SAE J1772/3**
Level 3	**480**	**400**	**192**	**60**	**three**	**N/A**

There needs to be safety standards for all electric vehicles. All electric vehicles needs their charging equipment examined for wear in plugs and sockets to avoid shock danger. In order for this to happen, you need to use the “Smart Chargers” (Rawson, 2012). This includes connection interlock, charge circuit interrupt device, automatic de-energy device, and ventilation interlock. All electric vehicles must undergo the same safety testing as conventional vehicles sold in the United States and they must meet the Federal Motor Vehicle Safety Standards (Maintenance). Battery packs must be sealed in shells and meet testing standards that are subject batteries to conditions such as vibration, extreme temperature, and humidity. Electric vehicles must be designed with safety features that deactivate the electrical system if a collusions or short circuit is detected.

If all electric vehicles were able to follow a universal standard, then this would make the integration of electric vehicles with the Smart Grid much easier.

Bi-directional Flow of Data and Electricity

The main purpose of the Smart Grid is to gather, manage and store data to improve the distribution of electricity to all the participants involved in energy consumption or distribution (Xi, 2011). For the Smart Grid to perform such a complex task, an efficient process of bi-directional flow of data communication must be established with electric vehicles. For successful communication between electric vehicles, the electric vehicles system operator (EVSO) and the Smart Grid, the Smart Grid must connect to a network like the Global System for Mobile Communication (GSM) (Benysek & Jarnut, 2011). Electric vehicle drivers can also communicate their information to the EV system operator so that the Smart Grid can better manage the distribution of electricity.

The communication network primarily communicates by exchanging data and information between the electric vehicle system operator charging terminal, electric vehicles, and driver (user) (Benysek & Jarnut, 2011). Smart apps are user friendly technologies which help electric vehicle drivers to manage and set schedules for charging their electric vehicle. This communication is essential to help increase the efficiency of the Smart Grid's distribution of electricity.

Whether or not electric vehicles are integrated into the utility grid, technical issues such as peak issues arise. This is due to the high demand for electricity during certain periods of the day which creates peak(s) on an electricity demand vs. time graph. This peak issue can grow even worse with the integration of electric vehicles into the utility grid. DeForest's research article shows that the issue of peak demand can worsen if electric vehicles are not managed by the Smart Grid or the EV system operator.

DeForest stated that peak issues have possible solutions such as careful management of electric vehicles in the Smart Grid through information gathering and controlling the charging time of electric vehicles. Benysek's and DeForest's research suggests that with the data gathering technology of the Smart Grid and the creation of incentives, tariffs, and other programs, technical issues such as peak issues can be resolved. As they describe, the bi-directional flow of data and electricity for electric vehicles will maintain a healthy Smart Grid and improve the Smart Grid's electricity management and distribution to participants.

Flow of Data Collection

Data in the Smart Grid travels bi-directionally from electric vehicles, drivers, charging terminals, and the EV system operator (Benysek & Jarnut, 2011). In Benysek's article on Poland's research it states that this data is managed by the EV system operator and the electric energy Distribution System Operator (DSO). Poland plans to use a Global System for Mobile Communication (GSM) or General Packet Radio Service (GPRS) for communication between drivers, terminals, and the system operator. GPRS is basically a cellular network for phone communication that will enable the easy wireless communication between drivers and the electric vehicle system operator.

This wireless communication network laid out in Figure 9 shows the bi-directional communication that is necessary for data transfer between the EV system operator and the electric vehicle driver (DeForest, 2009). Benysek stated that there are actually several levels of communication that take place in the Smart Grid between the electric vehicles, drivers, terminals, and the EV system operator. Benysek and Jarnut say the levels of communication which are described in Poland's research article on infrastructure are:

- Charging Terminal with EV System Operator
- Electric Vehicle with EV System Operator
- EV Drivers with EV System Operator

(NOTE: The EV system operator has to work with the electric energy Distribution System Operator (DSO) to manage the Smart Grid since Poland did not integrate them together.)

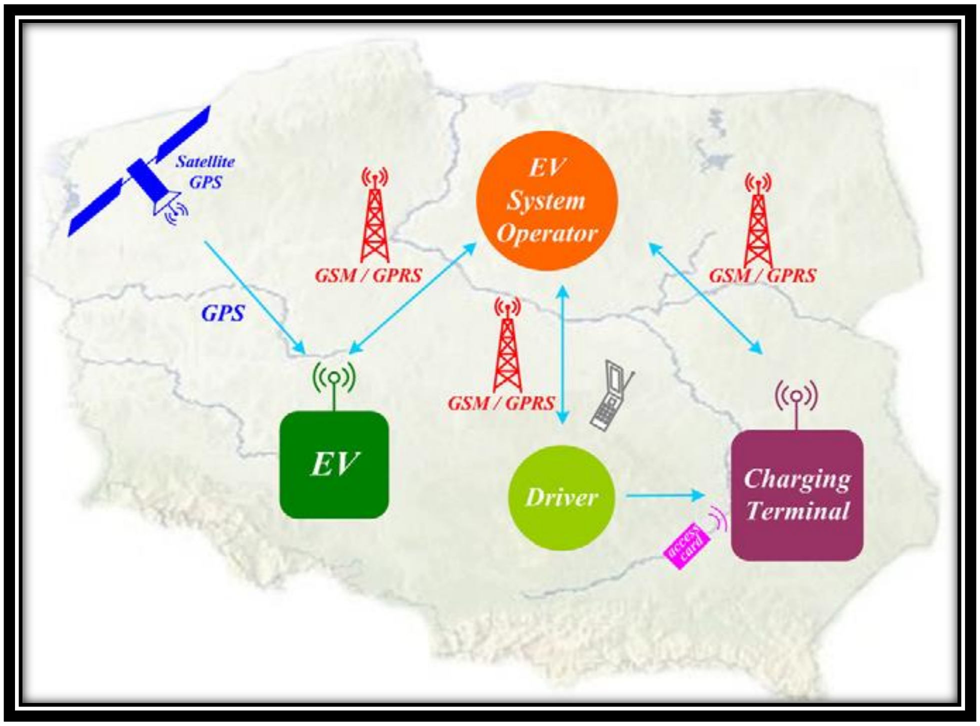


Figure 8: Communication in EV charging system in Poland (Benysek & Jarnut, 2011)

Charging Terminal with EV System Operator

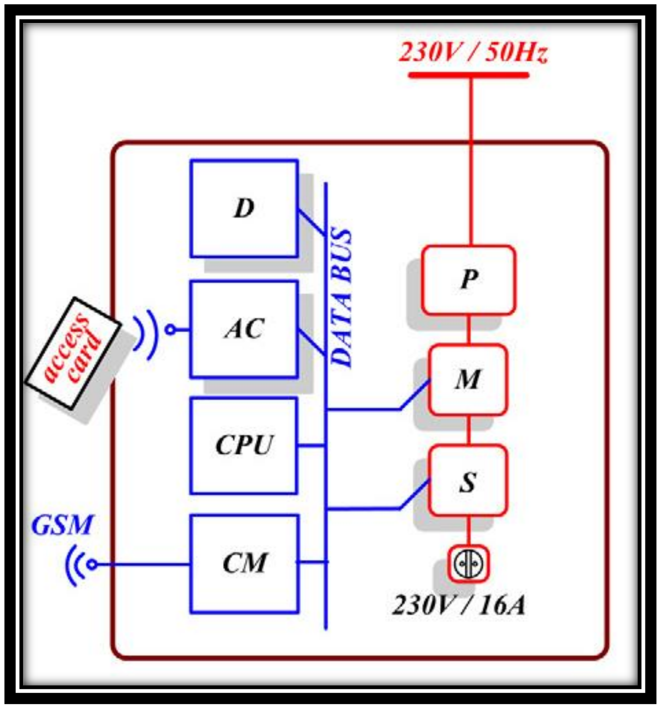
Benysek states that data transfer between the charging terminal and EV system operator communication is done by GPRS. The main purpose for the communication is for the EV system operator to manage the terminal and have the option to take action to change the action of turning “on”, “off”, or “limit” the electricity flow to the electric vehicles to better improve the Smart Grid health states Benysek. Benysek stated that the central processing unit (CPU) is able to change the switches, control the charging of charging circuit, and relay information of charging status to the EV system operator.

The EV system operator receives the technical status of the charging terminal which it manages and protects from theft and unauthorized access. Additionally, the charging terminal identifies the user that plans to charge their electric vehicle based on the magnetic proximity card. This card will notify the terminal and relay the information to the EV system operator about the electricity consumed by the electric vehicle. Benysek explains that the data which Poland's charging terminal will collect are the information of terminal status, users, and charging rate.

Though the information is mainly managed by the EV system operator, basic information is still processed in the terminal CPU. Benysek states that the terminal is designed with the ability to read the access card and then relay this information back to the EV system operator. Beside this the CPU is also responsible for computing that meters the pricing and performs communication tasks between the drivers input with the terminal.

Since the charging terminal is managed by the EV system operator, under certain circumstances the Smart Grid can introduce dynamic pricing for the consumers. Pricing information can be transferred to the CPU for processing and then billing to the consumers. This control over the terminal will also let the EV system operator better support the Smart Grid energy distribution if DSO works with EVSO (Benysek & Jarnut, 2011).

Figure 9 - This displays an example of a functional diagram of the terminal. As illustrated the terminal is capable of reading the access card and the CPU in the data bus is able to process basic information that comes from users and EV system operators through the GSM.
Image reference from:
(Benysek & Jarnut, 2011)



Electric Vehicle with EV System Operator

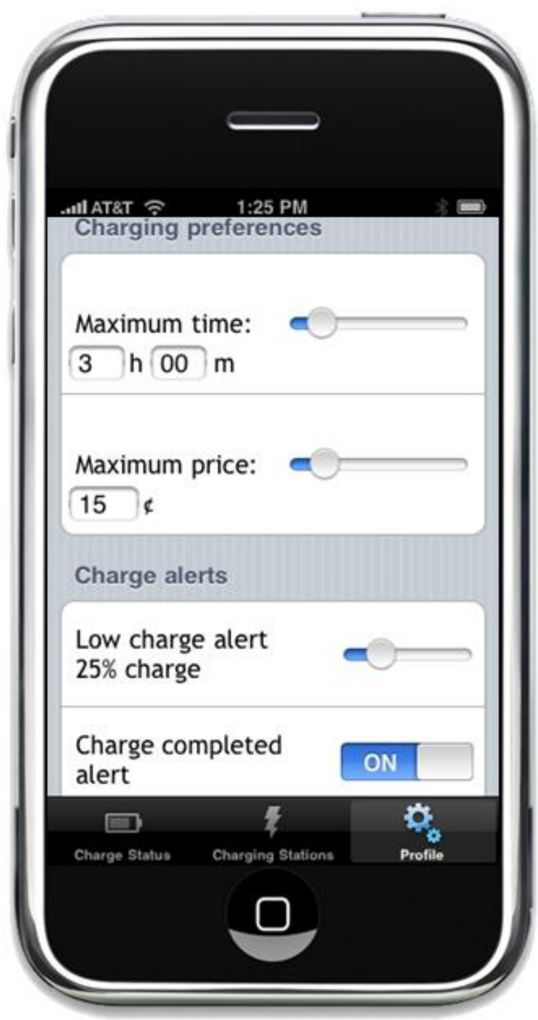
This is another level of communication that the Smart Grid can possibly enable electric vehicles to do. Communicating this process will help the EV system operator determine the electric vehicle identification information and current location. Jarnut states that the main information being communicated between the electric vehicle and EV system operator is the Battery Management System (BMS). This information will determine how the EV system operators and electric energy DSO, which controls the Smart Grid, manage electric vehicles' charging time to relieve technical issue like peak issues (Benysek & Jarnut, 2011).

Before this information is communicated to the EV system operator, the electric vehicle's internal BMS, including information of State of Charge (SOC) and Stage of Health (SOH), are gathered (Benysek & Jarnut, 2011). Controller Area Network bus (CAN bus) gathers this information. CAN bus is a vehicle bus standard designed to allow devices to communicate with each other within a vehicle without a host computer. Once gathered this information can be provided to the EV system operator.

Benysek states that this data is fed back to the EV system operator to help manage the Smart Grid electric energy distribution. With this information the EV operator can determine if the SOC is sufficient for that electric vehicle and switch the charging to another vehicle to maximize both vehicle battery charge energy. The EV system operator with SOC information can also discharge the battery electricity back to the grid for energy if SOC is sufficient for the consumer travel based on consumer's compliance.

EV Drivers with EV System Operator

This level of communication emphasizes the information transfer between the electric vehicle drivers and EV system operator as Jarnut states. At this stage radio frequency identification (RFID) help the terminal determine and authorize the drivers. Once authorized, charging of the electric vehicle can begin. At this same stage the driver can change or set their charging time, electricity consumption, price range and schedule with the EV system operator or terminal (terminal - depends on the technology that comes with the terminal if CPU is capable of complex management or not).This communication can be done in a few ways. One way is through a smart app that has been created to connect the



phone of the electric vehicle to the EV system operator or terminal. Other methods involve communication through the internet. Each of these methods is basically the same since the smart app basically connects the users to the internet where they edit their consumption (Benysek & Jarnut, 2011).

Smart Apps a Form of Data Scheduling

With smart app technology, phones are capable of sending information from consumers to the EV system operator through GPRS during the time window in which consumers charge their electric vehicle (Gadh, 2012). The smart apps allow the user to input basic information easily from their mobile phone. Information of charging prices and promotions can be provided within the smart apps on the phone once EV system operators create programs.

With this consumer friendly mobile smart app, an electric vehicle driver will have more control over the scheduling of their TOU for charging and in managing the scheduling of tasks from the mobile smart apps which communicate with the EVSO through GPRS (Benysek & Jarnut, 2011). Promotions, consumption reduction, and price rate reflected in a smart apps managed by the EVSO can help manage the peak issues and maintain Smart Grid health.

Figure 10 – Smart Apps on a phone. (Gadh, 2012)

Bi-directional Flow of Electricity

The main goal of the transfer-of-electricity method is to stabilize the grid's technical issues encountered such as peak problems, blackout, voltage, phasor, and frequency issues. These technical issues are already being researched, as the Smart Grid continues to develop along with EVs. The technical issues with EVs only occur if they are left unmanaged. The straightforward solution that comes out of this is a management system for EVs.

Smart Grid Peak Issues

The first of many problems that many utility grid companies anticipate is peak issues that are already occurring and that EVs might further push the demand of electricity pass the current peak (DeForest, 2009). As Gadh (personal communication, 2012) has stated, peak issues come from the high demand of electricity at certain times of the day where insufficient electricity provision occurs and therefore electricity must be supplied through other means beside power plants (which are much more expensive). These peak issues normally occur a few hours after noon when most people are using electricity. This can be confirmed from the CAISO CAMX (California Independent System Operator for the California- Mexico Power Area) graph (Figure 112). The black line on the CAMX figure shows average summer load or electricity demand during summer without EVs being implemented. The peak during around 3-4pm of this graph usually cost more to maintain because most grids need backup to supply excess energy to the grid if the peak capacity is passed.

Figure 112 is the example of peak load issues when EV charging is unmanaged and the worst case scenario results. Surpassing the electrical threshold (71GW) which the utility companies can provide will result in undesired consequences which the Smart Grid will have to face. Results of peak issues can be felt immediately through blackouts or brownouts as the Smart Grid cannot provide enough electricity (DeForest, 2009). Blackouts and brownouts are results of overworking the power plant to the point where its maximum output of electricity does not meet the load demands. These issues usually require utilities to quickly shutoff their power plant for safety measures rather than letting it overheat.

Another note toward CAMX (Figure 112) is the fact that this figure is only displaying 25% of Californian vehicles. This means that EVs implementation into the Smart Grid at 100% will make the situation worse. At 5% of Californian vehicles though, the demand of GW that EVs require plus the consumers' daily requirement will not surpass the regular max peak. This means EVs can be adopted at this level as long as it does not pass current peaks.

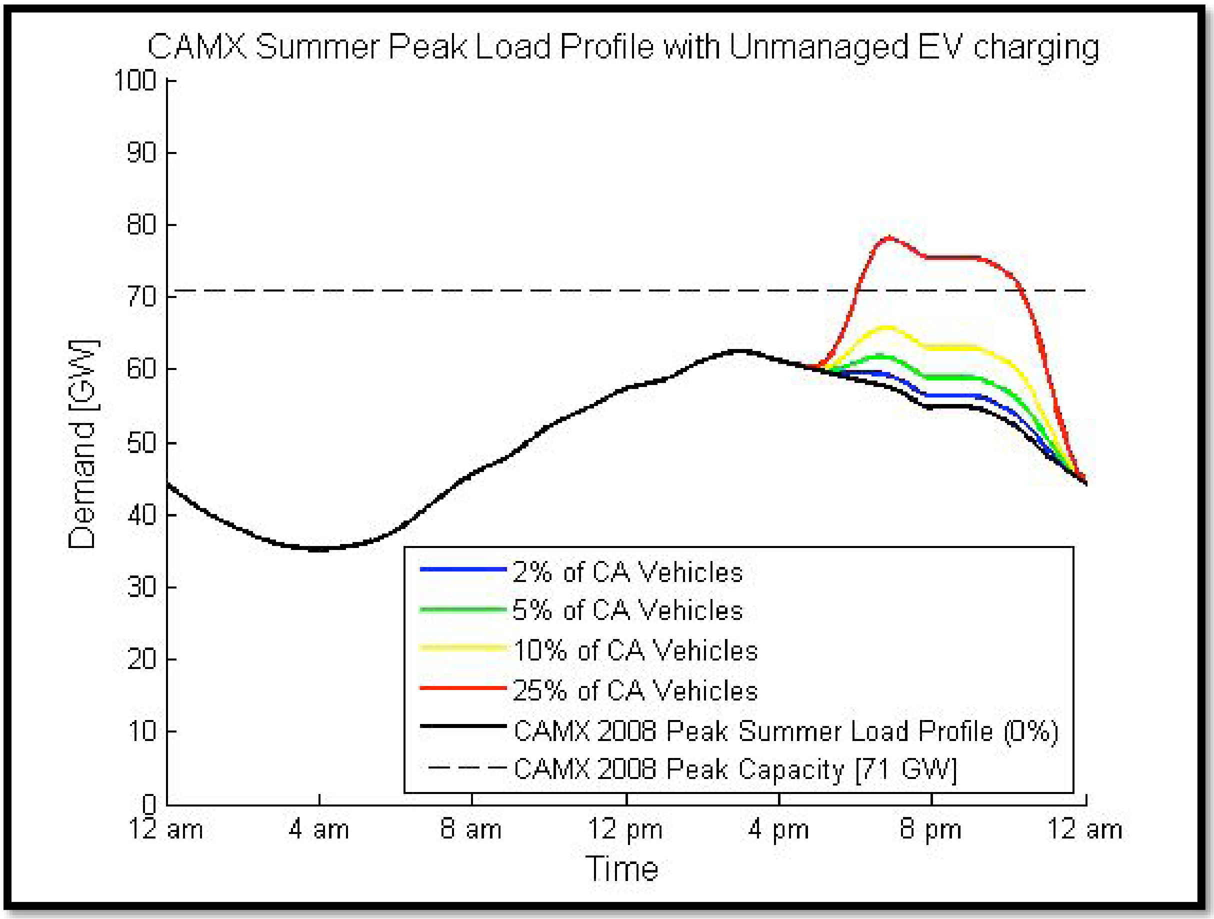


Figure 11: Demand vs. Time graph of unmanaged EV charging (DeForest, 2009)

The best possible scenario is to have constant demand and, therefore, no peak (DeForest, 2009). This constant demand is also favorable to the utility companies as well because it means they can produce the exact amount the consumer desires and therefore lower the cost to operate the power plants. The issues with EVs creating peak issues can, instead, be converted in to a possible solution if the management of EVs is done correctly in conjugation with the Smart Grid.

Solutions to Peak Issues

DeForest stated that if there is a management system (EVSO in this case) in the Smart Grid for EVs charging time, it can help prevent consumers from charging EVs during peaks hours. This technical issue of peak problem can be converted into a solution by using incentives such as cheaper night time electricity rates when demand is low and creating higher pricing for afternoon rates when demand is high. This method creates the idea of real time pricing where pricing of electricity depends on the demand by consumers similar to stocks in the stock market. Tariffs can also be implemented by the EV system operator to better manage the Smart Grid health and prevent peak issues.

These incentives can be provided by the utility companies to benefit themselves by preventing peak issues and operating cost of power plants when peaks issues arise (DeForest, 2009). A technical solution for relieving peak issues is called peak shaving or valley filling as DeForest have stated in the article. The method is to charge EVs or PH only during the valley of the demand as a function of time curve will relieve the Smart Grid of peak issues. This scenario can be seen in the CAMX Figure 13.

The constant demand method which utility companies greatly desire can be seen right away in this case if EVs are managed correctly by the Smart Grid or the consumers. With the increase during night time demand due to EVs and PHs consumption the demand at night time reach a similar level to that of the afternoon time. This technical solution will help the Smart Grid or utility companies manage their electricity level at a constant supply without unnecessary costs. Constant demands means constant supply so there is a much easier prediction of what supply of electricity must be made available for the consumers before it is asked for. This will relieve utility companies from excess or insufficient electricity (DeForest, 2009).

The idea behind this can be created through incentives that utility companies provide (DeForest, 2009). This could work since there will be benefits towards the utility companies after some time. Currently this does not take into account the possibility of EVs charging at night and discharging electricity during the day back to the utility grid to better manage the Smart Grid health. Figure 13 only considers the charging into the battery and not discharging from the battery to the utility grid.

The Smart Grid will give the possibility of two way communication and a bi-directional flow of electricity (Xi, 2011). This means that EVs implemented in the Smart Grid can draw excess electricity at night and release the electricity back to the utility during the day. Xi's research and DeForest's article explains that it is possible to relieve the Smart Grid electricity demand if night time battery are store in cars and then released during the day. If incentives are created for the Smart Grid to manage EVs charging during non-peak hours and discharging during peak hours are implemented correctly the stress on the utility grid can be nearly eliminated as described in the DeForest's article.

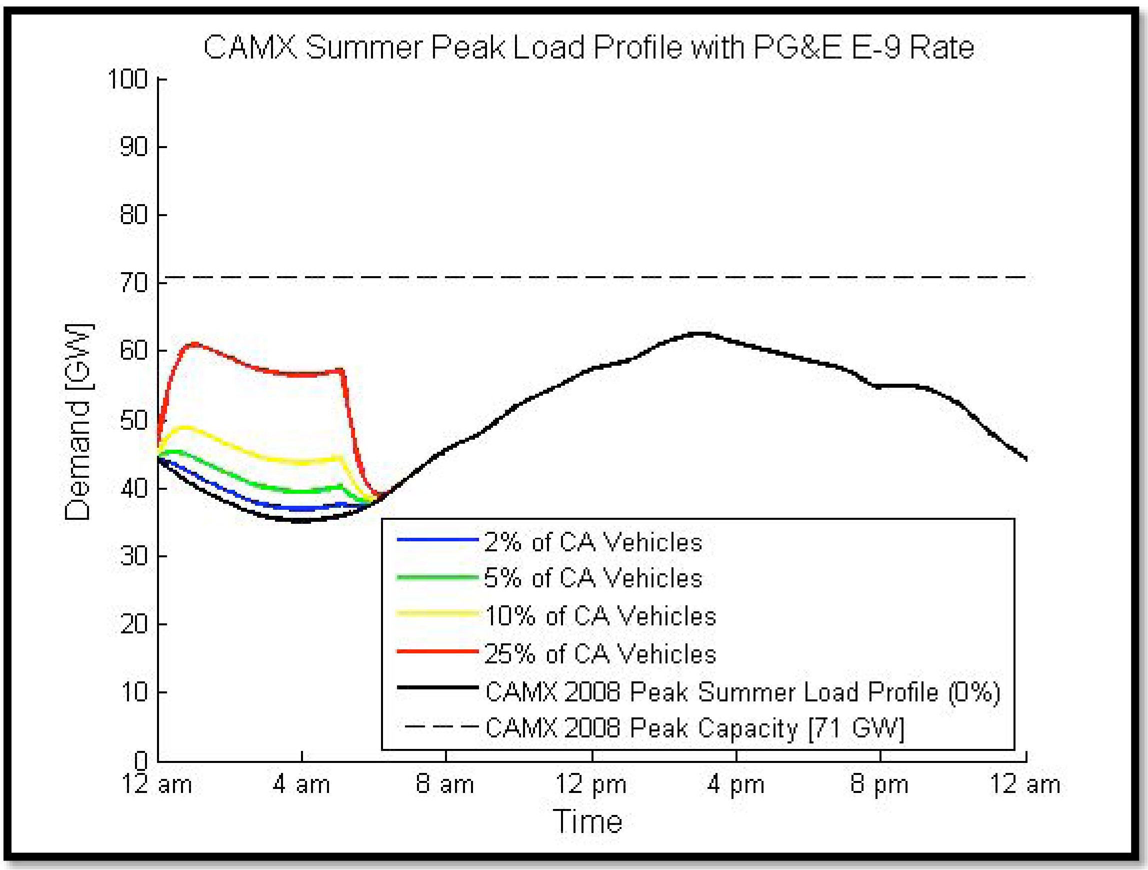


Figure 12: Demand vs. Time graph of Managed EV charging (DeForest, 2009)

Scenario & Cost – Benefits Analysis

The EV system operator's main objective, as described by Benysek, is to better manage the electric vehicle's electric energy consumption and health of the Smart Grid. To do this terminals' and users' data must be fed back to the EV system operator. Before EV system operator can be a fundamental function of the Smart Grid, costs and benefits of installation charging terminals, communication devices, and Smart Grid management must be proven to be functional.

Cons - Cost of EVs Implementation

First the projected implementation of the Smart Grid and basic management system are not yet fully functional or even implemented at all in many parts of the United States. In Glendale Water and Power's (GWP) implementation of their Smart Grid, they have already spent approximately $70 million based on their figures in class presentations (Steiger, 2012). For an EV system operator to operate our first step is to have a stable working Smart Grid. So for our scenario we will assume a working Smart Grid is already available for consumers to participate. Without this Smart Grid and communication network available building terminals and wireless network becomes much more difficult.

With the assumption of Smart Grid being available, basic communication devices are also available. For wireless communication that a Smart Grid requires, like Tropos, that GWP use, costs about $230 for pole mounting communication and $1000 for network management software gathered from Tropos site. This already becomes a huge burden financially. Though there are various communication methods, mesh seems more feasible in this case if it is to be integrated with other Smart Grid technologies anyways (Tropos Networks, 2007).

Tropos Networks states that for a small 34 sq miles in Manhattan the cost is already tremendous. If a Wi-Fi mesh network (Tropos networks) is implemented the price reaches about $2 million (prices are displayed in Figure 14). If 1x EV-DO (GSM – 3G) is used instead the price can reach $8 million.

Table 4: Manhattan network prices (34 sq. miles) (Tropos Networks, 2007)

	Cells	Cost	Performance
3G (1x EV-DO)	64	~$8M	⇩150-400 kbps ⇧ 10-50 kbps
Wi-Fi TROPOS networks	600	<$2M	500-2,000 kbps *symmetric*

The price of the charging terminals must also be added in. This ranges from a few hundreds of dollars for level 1, thousands of dollars for level 2, and tens of thousands of dollars for level 3 (EV Charging Essentials). These prices together add up to a few million dollars that must invested in communication, Smart Grid, and terminals to have a miniature stable Smart Grid with electric vehicles integration. To sum this up an EV system operator has a long way to go before coming to existence due to high cost to build and maintain the communication system of the Smart Grid and individual terminals.

Pros - Benefit of EVs Implementation

On the other hand, if all Smart Grid technologies are successfully built at a feasible price various benefits can come out of this electric vehicle – Smart Grid integration with the help of EV system operator. As discussed earlier the EVSO operates and manages all the incoming information and processes it in the best possible manner to benefit the consumers and the Smart Grid. This task that EVSO is given enable them to communicate with electric energy provider to eliminate peaks issues as Benysek described.

Benysek explains that the EVSO can communicate with the DSO to block, limit, or tariff charging terminals to protect the health of the Smart Grid and quality of energy distribution. These methods' benefits will be reflected in the lowering of peak issues if all goes as planned. Bi-directional flow of energy can also be managed by the EVSO with user confirmation to resupply the Smart Grid with electricity or just to prevent fluctuation in frequency, voltage, and phasor. This data and action can be acted on between the electric energy DSO and the EVSO as described in Benysek's article.

Together DSO and EVSO make up the basic management of the flow of data and electricity between electric vehicles and the Smart Grid (Benysek & Jarnut, 2011). This participation between the DSO and the EVSO is on a grander scale when compare to EVSO communication with terminals, electric vehicles, and users. But even communication between EVSO and its smaller component will enable it to maximize every person charging time and schedule. With this type of communication, Smart Grid will be able to avoid various technical issues and become more efficient in energy distribution.

Future Approaches and Weakness

Currently, Smart Grid throughout the U.S. is still at a weak stage of implementing wireless technology. As stated, Smart Grid being built now will have limited function and communication due to fear of investment; making this the biggest weakness of the Smart Grid. To implement EVs into the Smart Grid a stable grid system must be implemented first for wide EVs adoption and EVSO to participate in managing the EVs.

For future approaches the technological risks needs to be split out among investors. This method is highly possible since wireless communication which EVSO, terminals and users need to communicate can be integrated with other wireless technologies that will be looking forward to Smart Grid participation. Example of these investments can come from wireless communication of AMI and HAN which will need wireless networks.

Conclusion

For the integration of EVs into the Smart Grid, a huge consideration of how efficiency and distribution will play out within a Smart Grid is important. This efficiency and distribution, as explained, is split between EVSO, terminals, and users. By communicating with each participant in the Smart Grid better electric distribution can be achieved. Besides achieving better efficiency and distribution of electricity through the Smart Grid, information transfer can help prevent various technological issues like peak issues.

The main problem of EVs integration into the Smart Grid is the costs that come with it. As it turns out, DeForest and other researchers have stated that EVs implementation into the Smart Grid will require a high technological cost. Due to the current high costs of implementation EVs integration is still out of the picture for now. But, on the other hand, if risks can be distributed out to other Smart Grid technologies and investors, EVs integration can become much more realistic.

Acronym/Glossary

BMS – Battery Management System

CAN bus – Controller Area Network bus

CAISO CAMX – California Independent System Operator for the California- Mexico Power Area

DSO – Distribution System Operator

Electric Energy DSO – Electric Energy Distribution System Operator

EV – Electric Vehicle

EVSO – Electric Vehicle System Operator

GPRS – General Packet Radio Service

GSM – Global System for Mobile Communication

GWP – Glendale Water and Power

RFID – Radio Frequency Identification

SOC – State of Charge

SOH – State of Health

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