

A Methodology for Vehicle-to-Grid Communication

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Summary

Vehicle-to-Grid (V2G) technology optimizes the potential of electric and hybrid-electric vehicles in use by the general consumer. V2G is the practice of the vehicle owner selling power stored in the batteries of the electric vehicle back to the electric company. The electric vehicle owner can sell power to the utility during the high cost peak demand period and recharge the vehicle at the lower cost off-peak times. This allows the vehicle owner to reduce operating costs of the vehicle, and the utility has an alternative source of peak demand power.

This paper will present the communication required for an operating V2G infrastructure. Details of the communication channels from the utility, vehicle, charging station, vehicle battery charger and the vehicle owner will be presented to show the interactions required to complete a V2G transaction. Overview for each of these communication channels will include the test protocols and hardware requirements. The results are presented to show communication solutions for the V2G mode of operation.

1 Introduction

The benefits and economics of vehicle to grid, V2G, technology has been described in various papers and presentations showing the aspects of the energy storage capability available to grid. The basic premise of V2G is that electric vehicles are modified to allow reversible battery charging. This is so that the excess capacity of stored charge in the ever expanding fleet of electric vehicles becomes available to the utilities for use to supply peak demands. The electric vehicle fleet is charged at night during low demand times and partially discharged during the peak daytime hours. The vehicle owners also receive a benefit of buying electricity at the low off peak rate and selling the electricity at the high on peak rate. This buying low and selling high can potentially negate their total energy cost for their vehicle. Thus is the draw of V2G to both the consumer and the utility.

The communications infrastructure to make V2G technically and economically viable has not been implemented or fully determined. I will discuss some proposed components of a V2G communication infrastructure and how they interact. This proposed infrastructure will only detail one possible method that can be used, but it highlight all of the links needed in any alternate proposed arrangement. The hardware and software requirements of the proposed V2G communication infrastructure will also be touched upon before delivering a conclusion about the proposed path forward for V2G technology.

2 Components of a V2G Communication Infrastructure

The communications infrastructure to make a V3G system operate must have an interactive link between the consumer, his vehicle and the utility. This structure needs allow the consumer to make informed decisions about selling the excess energy in his vehicle, and it needs allow the utility to make informed decisions about when to buy the energy. The information needed and the communications required means that the electric vehicle must be the center point between the consumer and the utility. The vehicle knows how much charge it has available, and can predict the excess that the consumer can potentially sell back to the utility. The vehicle also has the available connections to send the request and response communication to both the consumer and the utility. Finally, the vehicle can supply information about its identification, specifications, current instrument readings, power connection, owner information, weather and current location.

Looking at the components needed within the electric vehicle, there is the initial change of the battery charger to be able to transfer energy bidirectionally between the grid and the vehicle's batteries. In addition to that, the vehicle would need several different communication interfaces. In the proposed system, three communication interfaces are used in the vehicle. Two interfaces are just to talk with the vehicle owner and the third interface is to talk with the utility. The first interface to the owner would be an in-vehicle communication component that could allow setup through the vehicle's displays and controls, and the second interface to the owner would allow the owner to update the settings when away from the vehicle. This second interface would need to connect to the web in order to link up with the owner's smart devices that could be used to change settings when away from the vehicle. The last communication interface in the vehicle would be to the utility. This interface would send the request to sell the electricity to the utility, receive the authorization from the utility, receive updates from the utility and send all metering information to the utility concerning the energy transfer.

The vehicle's second user interface, through the internet, would also require that components be made available for use with all connected media. The vehicle's owner would be able to use a DSL, Cable, Wi-Fi, Satellite or Cellular connected device to access the energy exchange menus within the vehicle in order to schedule, modify, cancel, or check the status of an energy transfer.

The next part of the V2G communication infrastructure comes in the form of communication to the smart grid. The standard electric watthour meter needs to have the capability of communicating with the electric service, and it needs the capability of communicating with any smart metered appliance behind it. In this case, the utility watthour meter needs to communicate with all of the electric vehicles that are connected behind the utility meter. The next section explains this interaction and why the utility watthour meter plays an important role in the V2G communication infrastructure.

Finally, the utility will need to have the proper communications interfaces connected to the grid to read the communication packets from the smart watthour meters and respond to the requests received. These utility nodes to the smart grid can be located at the medium voltage substations. From the substation smart grid nodes, the V2G communications can be converted to packets over standard internet communication to the utility headquarters where the decisions about approvals, time of transfer, amount of energy, and billing can be decided. All of the components are shown in the diagram below.

Figure 1. Components of the V2G Communication Infrastructure

3 Interactions of the V2G Communication Components

The initiator of any V2G transaction is actually the vehicle. The vehicle will monitor how much charge is left in the batteries and how much charge it will need to get home or to a charging station. The vehicle will inform the consumer, as part of a normal status display, how much excess charge is available in the batteries. Only if the vehicle determines that it is possible to make a V2G transfer will the vehicle's owner be asked if they want to make a V2G transaction with the utility. The vehicle's owner can then decide whether to use this excess charge or sell it. Thus the first interaction is always between the vehicle and the owner. The choice to the vehicle's owner must be kept simple and all of the calculations performed by the vehicle. The owner's decision can be presented as a two part question. First, are you going directly to a charging station or home on your next drive? Secondly, if so, do you want to sell your excess energy back to the utility at the peak rate? Other information, distances, possible destinations, and partial solutions should not be presented. Engineers love these options, but to the consumer, it would make the whole transaction confusing and can cause the loss of all consumer interest in V2G. Once the vehicle's owner has agreed to initiate the V2G transaction, the vehicle will inform him that it is being submitted for approval. The owner will receive notifications when the transaction is approved and when the transaction is completed. Up to any point before the transaction is completed, the owner will have the option to cancel the transaction.

Now that the vehicle's owner has initiated the V2G transfer request, the utility company must be notified that this transfer is available. Within this notification, the utility company needs to know the vehicle ID, owner ID, vehicle meter ID, vehicle grid connection location, amount of available energy and the time window to initiate the transfer. The vehicle has the information of the vehicle ID, vehicle meter ID, and amount of available energy. The owner transmitted his owner ID along with the time window for the transfer when the transaction was selected. This leaves only the vehicle grid connection location as the missing piece of information. Since this communication is being performed over the power delivery infrastructure, the vehicle sends the information it has to the watthour meter at the utility interface. The smart grid enabled watthour meter can read this information coming from behind the meter and retransmit it to the utility including its identification number. This identifies to the utility the exact location of the watthour meter and the V2G transfer. Now the billing can be correctly adjusted for the location that is receiving a V2G transfer of energy from behind the utility watthour meter.

The power line communications on the utility side of the watthour meter and on the facility side of the watthour meter are different formats. This separation allows a standardized format to be used for the facility side and the utility's choice of format for the grid connected side. The frequencies and packet structure used for the power line communications would be different for the utility and all of the smart appliances behind the smart grid utility watthour meter. This, along with filtering, would eliminate any possible interference between the two communication systems. The electric vehicle, considered a smart appliance once connected to the grid, would use a high frequency carrier that would have limited range and can be blocked from the distribution system by the watthour meter. This would be the same standardized communication that other smart appliances, such as air conditioning units, would use so that the utility could shut them down during load shedding. It is important to have a standardized communication format on the facility side for smart power connected appliances so that the V2G electric vehicles can connect with the utility from any smart grid connected facility. The watthour meter would always translate from the utility's distribution system power line communication to the metered facility power line communication.

Once the watthour meter transmits the V2G transaction request onto the smart grid, the transaction request is picked up by a power line communication node located on the medium voltage distribution and sent via a cable internet connection (or equivalent) to the Utility headquarters. At the Utility headquarters, the decision is made if the extra power is needed at the available times, and the vehicle owner's information is verified to certify the transaction. If approved by the Utility, an approval is transmitted back to the watthour meter which then transmits it to the electric vehicle. The electric vehicle notifies the owner that the transaction has been approved, and will wait until the Utility specified time to transfer the energy.

After the energy transfer, the electric vehicle will send a completion notice to both the Utility and the Vehicle's owner. The notice will contain the time of completion and the amount of energy transferred. When the Utility receives this completion notice, the facility's bill will be adjusted for the amount of energy that it received from behind the watthour meter, and the Vehicle's owner will receive a credit for the amount of energy delivered to the Utility. A nice feature at this point would be if the Utility would send back a message to the vehicle's owner listing the exact dollar amount of the credit. This instant gratification rather than waiting a month until the electric bill arrives would make the Vehicle's owner feel good about the just completed V2G transaction.

Figure 2. Communication Flow in a V2G Transaction

4 Test Setup of a V2G Communication Infrastructure

The test setup of the proposed V2G communication infrastructure is shown below in figure 3. The protocol picked to perform the power line communication for both the utility side and the facility side of the watt-hour meter is the IEEE 1901.2-2013 standard. The IEEE 1901.2 communication transceivers use a coupling capacitor to an isolation transformer connected to the power line and can operate in a frequency band of 10kHz to 500kHz in North America. For this system, the FCC-above-CENELEC bands of 154.69kHz to 487.5kHz will be used. The utility side of the watt-hour meter is set to the lower frequencies (155kHz in the test system), and the facility side of the watt-hour meter is set to a fixed 450kHz in the proposed system. The utility can pick any frequency, but the facility side must be a constant frequency so that a vehicle can connect and communicate anywhere in North America. All nine of the power line communication nodes in figure 3 are exactly the same. The controllers have a switch setting that changes them from the Utility frequency to the Facility frequency or both. The PLC controllers that are mounted with the watt-hour meter are able to receive and transmit on dual frequencies so they are set to handle both the Utility and the Facility frequency.

The watt-hour meter in the test setup is an inline current shunt resistor connected differentially to an A/D converter on a TI DSP. The watt-hour meter is tied to the AC line and is isolated through its power and serial communication lines. The exact same setup for the watt-hour meter is used for the meter in the electric vehicle. The AC line to the grid is metered in the electric vehicle. This gives an exact reading of the VA consumed and delivered from/to the utility. The isolated communication channels from the watt-hour meter are tied to the PLC controller associated with the watt-hour meter and to a user interface for the electric vehicle. The user interface panel allows the input of the V2G requests.

The communications from the facility side of the watt-hour meter cannot be allowed to be read by another facility's watt-hour meter. This would cause confusion as to which meter the electric vehicle is attached behind. To stop the facility PLC signals from reaching another watt-hour meter, high frequency notch filters are placed in the power lines. These notch filters are placed between the utility and the watt-hour meter. The notch filter center frequency is at 450kHz and the -40dB bandwidth is around 15kHz. This eliminates the PLC signals from facility grid connected appliances from getting onto the utility side of the watt-hour meter.

Figure 3: V2G Communication Test Setup

5 Conclusions

There are already over 250 million vehicles in use in North America; what if in 30 to 40 years, all of these were electric with at least a 90kWhr battery pack. The need for charging/discharging connections at work, shopping centers, restaurants and at home is no longer an option. Will the infrastructure be ready to handle all of these smart grid connected vehicles. After reviewing the communications required for a V2G transaction, the proposed pieces of infrastructure that are needed become evident.

1. Electric vehicles will become smart grid connected contain a PLC device.
2. Watthour meters need to be installed in electric vehicles. As the world changes from gasoline to electric, the energy costs of public charging will no longer be free. The meters should be installed in vehicles now to prepare for a larger electric vehicle charging infrastructure in the future.
3. There needs to be a different frequency band for behind the watthour meter PLC, and this communication must be isolated from other watthour meters.
4. The PLC behind the meter must be at a standard frequency and have standard communication packets for all smart grid connected appliances.
5. Utilities must start planning for billing the meter behind the meter. When thousands of electric vehicles show up at a factory and plug in during the day, the proper owners need to be billed for usage or credited for supply if V2G capable.

It is definitely evident that this is not going to happen overnight. It is a long implementation process that takes a lot of foresight by the standards committees, regulators and utilities to have implemented in the future.

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