Plug-In Hybrid Vehicles, Wind Power, and the Smart Grid

Presented at:
EUEC Energy and Environment Conference
Tucson, Arizona
January, 2008

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Numerous recent articles have addressed the benefits of plug-in hybrid vehicles, and the benefits of a smarter electric grid. These two concepts fit together incredibly well, but well-defined standards are required to optimize the economic opportunity presented by this combination.

Plug-In Hybrid Vehicles

Hybrid vehicles like the Toyota Prius use relatively small batteries to provide low-speed and starting power, switching to gasoline for distances over a few miles and speeds over about 25 mph.

Plug-in Hybrid Electric Vehicles (PHEVs) are being developed with larger batteries that will charge during off-peak hours, and allow the driver to use exclusively electric power for 30 – 50 miles of driving, switching to gasoline for longer trips. PHEVs offer customers the opportunity for fuel at gasoline-equivalent prices of less than $1.00 per gallon.

In order to travel at freeway speeds, PHEVs will require about 8 kW of electrical capacity that can be delivered to the drive train. However, if they are to be charged on 110 Volt home circuits, they can only have about 2 kW flowing from (or to) the grid over a residential circuit. At a modest additional cost for residential 220 Volt wiring, they could be fitted with 8 kW grid connections.

Wind Power

Wind power is a very desirable addition to the utility grid. It is renewable, economical, reliable over the course of a year, clean, and domestic. Advances in wind power technology have reduced bird mortality and greatly improved system integration issues.

The biggest remaining challenge, however, is that the wind does not always blow at the hours of the day when power loads are highest, and “shaping” wind energy to meet customer demands currently means reliance on either expensive pumped-storage, expensive compressed-air storage technology, or expensive and polluting fossil fuel usage. Finding a complimentary resource to provide storage to shape wind energy remains very desirable.

The Smart Grid

Many articles have discussed the advantages of a "smart grid" that can communicate in real time electricity prices, and send signals to equipment to reduce loads on short notice.

The "smart grid" includes advanced utility Supervisory Control and Data Acquisition (SCADA) systems that can keep track of thousands of data points of loads and resources, smart meters that can communicate to the utility SCADA center, and smart appliances that can respond instantaneously to economic or reliability imperatives.

Most of the discussion of the smart grid has focused on loads like residential and commercial space conditioning, water heating, and industrial processes that are cost-effective to interrupt during periods of high market prices. There is growing discussion regarding integrating the smart grid with new loads like PHEVs.

Putting Two and Two Together.

The combination of benefits of PHEVs, Wind Power, and a Smart Grid are immense. Imagine the scenario:

- On a normal day, you wake up in the morning, and your PHEV is fully charged on low-cost off-peak power at $.05/kWh, the equivalent of gasoline at less than $1.00 per gallon. You plug it in at work, and it recharges during the shoulder hours of the day, and you're fully charged to drive home. Both trips are on electric power. You save half the normal cost of gasoline.

- But, today is a little different. Before you wake up, the grid operator knows that today will be hot, and loads will be high. Your car receives a signal from the grid via either cellular or wireless technology that power prices are expected to exceed the price of gasoline that morning, and again in the afternoon. Your car automatically tells you it has selected to use gasoline power for the morning commute, to conserve your batteries.

- You arrive at work and plug back into the grid. For the next hour and a half, the grid draws down all the stored energy in your batteries dry, providing 8 kilowatts and 12 kilowatt-hours into the grid. Your "account" is credited at $.20/kWh for that power, up to <u>four times what you paid to charge it overnight</u>. It is also above the replacement cost of gasoline you might require if you need to get into your car during the day.

- At 10 AM, power prices subside, and the grid starts recharging your car, but this time it's more expensive mid-day power at $.10/kWh, but still cheaper than gasoline.

- At 3 PM, you batteries are fully charged, ready to take you home. At 4 PM, a major generating plant fails. The grid calls on your batteries as a form of spinning reserve, to replace the power of the failed generating plant.

- The grid operator determines that the system can meet demand until 5 PM by relying on PHEV power, and does not need to start up a reserve generating plant, as it determines it will be cheaper to draw down PHEV batteries on-peak, and let people drive home on gasoline that day. Your batteries are depleted when you leave work.

- You leave for home, and your PHEV runs on gasoline, recharging your batteries to 3/4 capacity. Arriving at home around 5:30 PM, you plug back in, and the grid draws down the last power in your batteries before loads subside in the evening. Your account is again credited at $.20/kWh for this power.

- Overnight, your car fully recharges on low-cost off-peak power. You are ready for another day.

- The prior scenario would be similar for a summer peaking utility except for the timing of peak demands.

Look at some of the benefits of this PHEV / Smart Grid system.

- The customer gets the benefit of low-cost electricity for a transportation fuel, but automatically switches to gasoline when the electric power is more valuable to the grid than it is to the vehicle. The customer is <u>guaranteed</u> to save money, since their batteries automatically are charged when electricity is cheaper than gasoline, and only discharge into the grid when the payment the consumer receives <u>is</u> higher than the cost of gasoline they <u>may</u> need to burn to recharge depleted batteries.

- The grid gets the benefit of 2 - 8 kW of spinning reserve per PHEV throughout the business day and again in the evening, when the cars are either drawing on the grid (and can be interrupted) or resting fully-charged on the grid and can be called upon to feed the grid. Even at 3 AM, the spinning reserve benefits of these batteries can be significant.

- The utility avoids the cost and environmental impacts of running a peaking power plant partly loaded to provide spinning reserve.

- The utility benefits from this “spinning” reserve that is reliable and instantaneous. (i.e. there are no failures to start or waiting several minutes for combustion turbines to be brought on-line)

- The utility and its customers benefit from avoiding expensive combustion turbine start-up and running costs. Minimizing starts and run-time would also significantly reduces maintenance and associated cost.

- The utility has a market for low-value, low-cost off-peak power, and its baseload power plants can run more economically.

- The utility has a source of low-cost, low-emission peaking power, and can avoid running more expensive power plants that generate more air pollution and carbon dioxide.

- In Southern California, about 1 million new cars are sold each year. If 10% of these were "Smart PHEVs" some 100,000 would be added each year. After 5 years, there could be up to 500,000 PHEVs available to the grid. If these were 2 kW connections, using existing 110 Volt circuits, the grid operator would have up to 1,000 megawatts of capacity available; if they were 8 kW connections using 220 Volts, the grid operator would have up to 4,000 megawatts of capacity available. The potential reserve capacity is truly amazing.

Adding Wind Power to the Equation

Your utility has acquired a large wind farm, enough to meet 25% of its load when the wind is blowing. When the wind suddenly dies down, it needs to be able to quickly turn to a reserve on-line generating facility. Currently this is generally done by keeping a natural gas fired power plant operating at part-load, that can be brought up to full load in a few minutes. The unit has lower efficiency at part-load, and more fuel is used in addition to producing more air emissions and carbon dioxide.

With thousands of "smart PHEVs" connected to the grid, the grid operator knows exactly how many PHEVs are plugged in and available for dispatch. When the wind dies down suddenly, they can immediately draws on the PHEV batteries as spinning reserve to make up the lost generation.

Over the next few minutes, they make a decision how to fill the resource gap. That decision is based on whether the wind is expected to pick up again, and on projected loads and the status of other resources. If it is morning, and loads are rising, it might mean starting an intermediate or peaking gas-fired unit a little earlier than would otherwise be needed. But if it's evening and loads are dropping, they might choose to draw down the PHEV batteries, knowing they can start recharging them with off-peak power after a short while.

Here, the PHEVs serve as a battery that can effectively store wind power when it is available for use when it is needed. Because the grid operator has a diverse set of resources available, and a complex set of choices, both the wind farm and the PHEV batteries are just treated as individual resources, not as a single system, but the economic and environmental benefits are equal (or greater) than if they were dispatched as a single system.

What Is Needed To Make This Dream a Reality

What are the components that the automobile industry and the electric power industry need to provide in order to make this vision a reality? There are many components, but none are beyond the capabilities of today's electronics and communication networks.

- A grid control system (i.e. the SCADA/EMS system) that tracks the real-time marginal / incremental cost of electric power, as well as the status of all generating units and reserve requirements.

- An automobile charging system including controls that can telecommunicate via cellular or wireless networks, so it can report its state of charge and receive information on whether to charge or discharge. Also the flow of energy and capacity must be metered.

- Plug in locations at work and at home that can handle the larger transfers of power – up to 8 kW – that each PHEV can provide.

- A communication network between the grid and millions of automobiles, so that the benefits of spinning reserves and the ability to deliver hundreds of megawatts into the grid can be realized. This system could possibly utilize cellular phone or wireless network technology.

- An accounting system so that the customer's electricity account is properly credited with the value of benefits they provide to the grid, and charges them for the electricity they receive from the grid. This will need to be capable of operating across utility service territories, so the customer can charge at home, for example, on Burbank Water and Power, and discharge at work into Los Angeles Department of Water and Power.

- If large numbers of PHEV's are to be housed in one location or parking structure, the infrastructure electrical system must be sized to accommodate the large magnitude of power that charging or discharging multiple PHEV's would require. Interactive real-time vehicle and utitlity control systems could also address this problem.

- Another practical problem that must be solved is to track how PHEV's are connected to the distribution system and insure that connection of PHEV's will not result in problems caused by excessive phase imbalance. Excessive Phase imbalance can trip a distribution circuit, so this is a problem that can be addressed by an on-board communication module in concert with a utility-based communication/control system. Early-on, phase imbalance will likely not be a major problem, but it certainly could be when market penetration of PHEV's increases to the millions. It could pose a problem anywhere large corporate fleets of PHEV's are parked and recharged or discharged in a fleet garage/parking structure.

How Far Are We From This Reality?

Nearly all of the components of this system are available today, but a single national specification is needed so that all of the PHEVs can work with all of the major electric grids in the country.

Some examples of the technology we use already:

Toyota produces the HV-M4 hybrid minivan in Japan, which provides 8 kw of electric power through normal household outlets on the vehicle; this vehicle is a favorite of construction contractors. They drive it to the worksite and plug their tools into it, cycling the van's engine as needed to keep the battery charged to operate their equipment. Constructing millions of PHEVs with this capability is possible with today's technology.

Cellular communication companies keep track of the whereabouts of over 100 million mobile phones on a minute-to-minute basis. They deliver calls, email, stock prices and sports scores to many of them. They bill each of them for the amount of service actually taken. In the case of prepaid phones that sell for as little as $20 each, they keep track and communicate exactly what the account balance is in real-time, automatically charging extra for roaming services where applicable. It is not much of an evolution to adapt this technology to communicate between the grid and millions of vehicles as needed if control and communication systems no more complex than a cellular phone were embedded in the automobile.

Modern utility SCADA/EMS systems and grid control systems such as those operated by the California Independent System Operator can provide minute-to-minute marginal power prices, and the status and availability of reserves to utility grid operators. They display in real-time what resources are available for dispatch. Adapting these to be capable of sending signals to PHEVs to charge or discharge is possible.

Installing the grid interface plug-ins for millions of vehicles would require a significant amount of electrical work, but using technology and skills that are readily available.

What Do We Need to Do Next?

- First and foremost, a standard specification for PHEVs to allow the electric grid to communicate with them, and to allow them to be easily plugged in at home and at places of employment are needed. The specification would cover the communications requirements, protocols, the power connection requirements, and the provision for accounting and billing information to be transferred.

- Second, rapid deployment of plug-in installations would be needed. Ideally, the specification would provide a method for the vehicle to automatically plug itself in when parked in a space with plug-in capability, and to automatically disconnect when the vehicle is turned on to drive away.

- Third, developing the accounting system and communication protocols to make the system work are needed.

- Fourth, programs to upgrade the communication capabilities and data handling capacity of the SCADA/EMS systems of the nation's electric grid are needed. A

PHEV owner needs to be able to charge their vehicle overnight on the utility system serving their home, but also be able to feed power to and purchase power from the utility serving the location where they spend the workday.

- Fifth, changing the reserve operating protocols for electric utilities is needed, so that the grid can rely on batteries instead of lightly-loaded power plants for spinning reserves and minimize start-up and running more expensive combustion turbines.

- Changes to the National Electrical Code may be required, so that PHEVs can recharge on residential circuits that MIGHT become overloaded if the homeowner turned on too many appliances at once. A smart residential meter should be able to communicate to the utility's SCADA system that it is close to its limit, and the SCADA system would shut down the PHEV charging until the range, dryer, air conditioner, or other large loads subside.

- PHEV owners charging locations on each utility's system could be tracked on the both the customer information system (CIS) and the utility's geographic information system (GIS). If the GIS system were linked to the utility's SCADA/EMS system, PHEV's could even be used to temporarily relieve specific distribution circuit overloads. Today, many utilities have their GIS system linked to their SCADA/EMS system or are in the process of doing so.

None of these are too complicated for today's auto manufacturers, utilities, communication providers, or electrical contractors. It just requires that we plan ahead, develop all of the vehicle, electrical, and communication infrastructure, protocols, and accounting systems, and then launch the system gradually, working out the bugs as we go.

There are recent exciting developments in the evolution of PHEV's and the ability to manage them. Toyota, Honda, GM and Ford have all introduced either new conventional hybrid vehicles or concept PHEV's with their entry into the consumer market by 2010-2011. Battery technology is also steadily improving as well.

Many utilities across the country are testing PHEV's today and smart grid technology including Burbank Water & Power.

A new start-up company, V2Green has partnered with Xcel Energy to test their Vehicle Control Module (VCM) in six Ford Escape Hybrids converted to PHEV's. Their VCM is a protype of exactly the system that would provide the full range of benefits that PHEV's could offer to both consumers and utilities alike. This technology has world-changing implications.

Smart meters, smart cars, smart utilities, and smart consumers can work together to make our economy stronger, our environment less polluted, reduce green house gas emissions, and make our lives more comfortable. The potential for a smart grid working with smart PHEVs is too great an economic and environmental benefit to pass up.

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