Effects of Plug-In Hybrid Electric Vehicles on the Vermont Electric Transmission System

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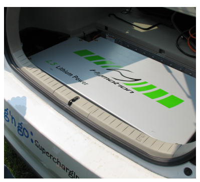
Abstract

Plug-in hybrid electric vehicles (PHEVs) have emerged as a near-term technology to reduce the nation's dependence on imported petroleum, address rising gasoline prices, and reduce carbon emissions from the transportation sector. This paper presents the results of a PHEV grid impact study for the State of Vermont—a small power system with peak demand of approximately 1 GW. The study looked at three different PHEV penetration rates and three different charging scenarios. Uncontrolled charging regimes--even at a low PHEV penetration rate of 50,000 vehicles (~ 9% of the Vermont light duty vehicle fleet)--could lead to an increase in the peak demand for electric power in Vermont. However, a delayed nighttime charging regime could accommodate 100,000 PHEVs without adding to system peaks. Furthermore, next generation smart grid technology using optimal charging algorithms could accommodate 200,000 PHEVs, or approximately one-third of Vermont LDVs. As previous studies have found, displacing conventional ICE vehicles with PHEVs can reduce GHG emissions and decrease consumer fuel costs.



Background

The researchers developed a PHEV vehicle profile with an electric range of 20 miles and a charge time of six hours.

TABLE 3 PHEV 20 Technical Specifications for Vermont Study

Nominal Battery Pack Size (kWh)	7.5
Usable Energy in Battery Pack (kWh)	6
Round Trip Battery Efficiency (%)	85
Charger Efficiency (%)	82
Charge Rate (kW)	1.4
Time for Full Charge (hours)	6
Purchased Electricity per Charge (kWh)	8.4
Electric Efficiency (miles / kWh)	3.49
All Electric Range (miles)	20

Table 4 lists the MW demand and total energy for each scenario and provides comparisons of PHEV energy requirements and contribution to peak demand based on total electric energy consumed in Vermont in 2005.

TABLE 4 Demand and Energy Assessment for Three PHEV Penetration Scenarios

	50,000 PHEVs	100,000 PHEVs	200,000 PHEVs
Demand	74 MW	148 MW	297 MW
% Summer Peak (1,038 MW)	7.15 %	14.30 %	28.59 %
% Winter Peak (1,054 MW)	7.01%	14.03 %	28.05 %
Daily Energy (1 charge per day)	445 MWh	890 MWh	1,781 MWh
Annual Energy (1 charge 365 days)	162,498 MWh	324,996 MWh	649,992 MWh
% 2005 MWh (6,325,960)	2.57 %	5.14 %	10.27 %
Daily Energy (2 charges per day)	890 MWh	1,781 MWh	3,562 MWh
Annual Energy (2 charges per day)	324,996 MWh	649,992 MWh	1,299,984 MWh
% 2005 MWh (6,325,960)	5.14 %	10.27 %	20.55 %

Charging Scenarios

Figures 1 and 2 (Uncontrolled Evening Charging): In this scenario it is assumed that the vehicle owner begins charging the vehicle upon arriving home from work. Charging start times are evenly distributed between 6:00 pm, 7:00 pm, and 8:00 pm. Each PHEV charges for 6 continuous hours.

Figures 3 and 4 (Uncontrolled Evening Charging/Twice Per Day Charging): This scenario represents the worse case, whereby uncontrolled charging in the evening is paired with daytime charging. The daytime charging start times are evenly distributed between 8:00 am and 9:00 am. The evening charging times are evenly distributed between 6:00 pm, 7:00 pm, and 8:00 pm.

Figures 5 and 6 (Delayed Nighttime Charging): This scenario assumes that either off-peak rates for PHEV charging or direct load control are used to delay PHEV charging times until 12:00 am. It is assumed that the entire PHEV fleet begins charging at midnight and ends at 6:00 am.

Figures 7 and 8 (Optimal Nighttime Charging): This represents the best case scenario from the grid operator's perspective. The vehicles are charged in a pattern that increases utility load factors by charging during the periods of lowest demand. Utilities are assumed to have next generation smart grid technology using optimal charging algorithms to control charging regimes. This scenario illustrates the possible beneficial load-leveling effects of PHEVs.

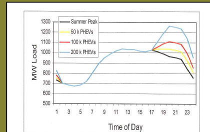


FIGURE 1 Summer Peak PHEV Load Impacts: Uncontrolled Evening Charging

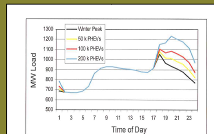


FIGURE 2 Winter Peak PHEV Load Impacts: Uncontrolled Evening Charging

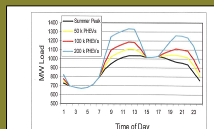


FIGURE 3 Summer Peak PHEV Load Impacts: Twice per Day Charging

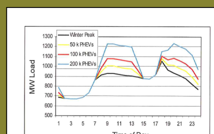


FIGURE 4 Winter Peak PHEV Load Impacts: Twice per Day Charging

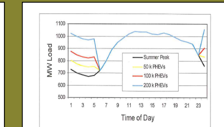


FIGURE 5 Summer Peak PHEV Load Impacts: Delayed Nighttime Charging

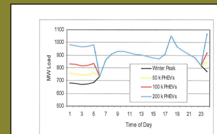


FIGURE 6 Winter Peak PHEV Load Impacts: Delayed Nighttime Charging

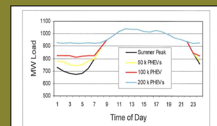


FIGURE 7 Summer Peak PHEV Load Impacts: Optimal Nighttime Charging

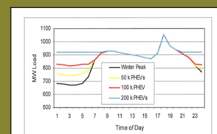


FIGURE 8 Winter Peak PHEV Load Impacts: Optimal Nighttime Charging

Acknowledgments

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Summary

A large fleet of PHEVs could be accommodated in Vermont without the need to build additional generation, transmission, or distribution infrastructure. However, this would require either financial incentives for off-peak charging, or direct utility control of PHEV charging. Simple delayed charging beginning at 12:00 am and ending with a full charge for the morning commute could accommodate over 100,000 PHEVs, or 17 percent of the Vermont light vehicle fleet, without adding to the system peak. PHEV fleets over 100,000 would require some form of direct utility control to ensure that the additional PHEV load would come during the off-peak hours to avoid adding to the peak power demand in Vermont.

Conclusions

1. A large fleet of PHEVs could be accommodated in Vermont without the need to build additional generation, transmission, or distribution infrastructure.
2. This would require either financial incentives for off-peak charging, or direct utility control of PHEV charging.
3. The uncontrolled charging scenario in most cases would add to the system peak.

Future Research

- Further research is needed to more fully understand PHEV drivers' travel behavior and performance of PHEVs in Vermont, and to compare them to suitable reference vehicles.
- Another area of considerable interest is vehicle-to-grid capability where utilities use the energy stored in parked PHEVs as load leveling devices. Additional research is needed to investigate the potential benefits of this technology given reasonable assumptions about the deployment rate of new PHEVs.