THE POTENTIAL IMPACT OF PLUG-IN HYBRIDS ON THE ELECTRICITY MARKET IN ILLINOIS

Audun Botterud, Argonne National Laboratory, Phone +1 630 234 8854, E-mail: abotterud@anl.gov
Linda L. Gaines, Argonne National Laboratory, Phone +1 630 252 4919, E-mail: lgaines@anl.gov
Guenter Conzelmann, Argonne National Laboratory, Phone +1 630 252 7173, E-mail: guenter@anl.gov

Overview

The transportation sector is the largest carbon emitting source in the U.S. economy. The U.S. fleet of light- and heavy-duty vehicles is also a major contributor to emissions of carbon monoxide, hydrocarbons, nitrogen oxides, and particulate matter, as well as local ozone issues. In addition, the transportation sector is the driving force behind the U.S. need for petroleum imports. With oil prices currently at record highs, a significant share of U.S. research and technology development is dedicated to reducing the petroleum dependence of the sector and the nation, as well as reducing transportation-related pollution. These challenges are being addressed on a number of fronts, including improvements in fuel efficiency, as well as development of vehicles that use fuels other than petroleum.

Given recent advances in lithium-ion batteries, one of the alternative vehicle technologies presently receiving much attention is plug-in hybrid electric vehicles (PHEVs). PHEVs could potentially play an important role in the future U.S. transportation system. A large-scale introduction of PHEVs would also have a substantial impact on power systems and electricity markets. In this study, we ran a set of simulations to analyze the potential impact of PHEVs on the electricity market and the power transmission system in Illinois.

Methods

Using results from the Multi-Path Study (Patterson et al. 2007) we forecasted the additional load from PHEVs in Illinois under several different assumptions about PHEV penetration (12.5 to 25 % of the light duty vehicle fleet) and time-of-day charging patterns. The base case represents the conditions in the Illinois electricity market in 2007 with no additional loads from PHEVs. We focused on three weeks representing low (spring), medium (winter), and high (summer) load conditions.

We used our Electricity Market Complex Adaptive Systems (EMCAS) model (Conzelmann et al. 2004) to run electricity market simulations with a detailed representation of the power system in Illinois. EMCAS can calculate hourly locational marginal prices in each individual transmission node based on a linearized power system dispatch algorithm (DC-OPF).

The input data for the power generation and transmission system represents the conditions in 2007. We included more than 1,800 transmission nodes within Illinois and 52 nodes outside the state. In total, we used more than 2,500 transmission lines and 230 thermal generating units in the data set. We focused on the impact of PHEVs on prices in the Chicago area and in southern Illinois. In addition, we analyzed the changes in system dispatch resulting from the additional electricity consumption from PHEVs.

Results

Our analysis of the impacts of a potential large-scale introduction of PHEVs on the Illinois power system shows that the load pattern would change considerably in such a scenario. The night-time load would increase substantially. The day-time load could also increase if a significant amount of the PHEV charging takes place during the daytime. This would clearly have an impact on the operations of the Illinois power system. For instance, in the low-load week, the additional loads from PHEVs almost levels out the typical day/night pattern in the original load data, if most of the charging is assumed to take place at night.

The results of our simulation analysis also showed that the large-scale introduction of PHEVs would have a significant impact on prices. The price changes would depend on the amount of energy required for PHEV charging and the time of day at which charging would take place. In general, the PHEV loads level out the difference between day- and night-time prices. However, the impact on prices varies between regions in Illinois, because of transmission constraints in the power system. The price increase is most profound in the area around Chicago, since this is a load pocket with limited transmission capacity.

We also analyze the change in the dispatch of the power system in Illinois due to the additional electric loads from PHEVs. In the low- and medium-load weeks the increase in load due to PHEVs is almost exclusively met by an increase in coal generation. In the high-load week we also see an increase in the natural gas fired generation. Nuclear and hydro generation is constant for the respective weeks since these resources have low operating costs and are therefore first in the loading order. An interesting observation is that the amount of imports actually decreases as a function of more PHEV load. This is probably due to the large share of baseload nuclear and coal plants within Illinois, which can also serve additional PHEV loads outside of the state.

Since most of the additional load from PHEVs is met by coal generation, there would be a substantial increase in the CO2 emissions from the power system in Illinois. On the other hand, if we consider future expansion of the power system the increase in night-time load due to PHEVs may result in more nuclear generators being added as base-load generation. This could obviously lead to a reduction in CO2 emissions from the power sector. The impact of generation and transmission expansion was outside of the scope of this analysis but will be addressed in future follow-on studies.

Conclusions and Extensions

In conclusion, we found that the current power system in Illinois potentially could accommodate a large-scale introduction of PHEVs, if most of PHEVs charge their batteries at night. However, the additional electric load from PHEVs is likely to have a significant impact on electricity prices, especially in the congested Chicago area. Furthermore, with the current system configuration most of the additional load due to PHEVs would be met by increases in coal generation.

Finally, we would like to emphasize that this is an initial analysis of the consequences of PHEVs on the Illinois electricity market. We are working on expanding the analysis in a number of interesting directions, including: (1) looking in more detail at the environmental consequences of PHEVs, and particularly greenhouse gas emssions, (2) analyzing how the optimal mix of power generation technologies would change as a result of the additional electricity demand from PHEVs, (3) analyzing in more detail the potential impact of PHEVs on transmission congestion and the need for new transmission lines in Illinois, and (4) calculating the economic impact for the various participants in the electricity market (e.g., generating companies, transmission & distribution companies, consumers).

Acknowledgement

The submitted manuscript has been created by UChicago Argonne, LLC, Operator of Argonne National Laboratory (“Argonne”). Argonne, a U.S. Department of Energy Office of Science laboratory, is operated under Contract No. DE-AC02-06CH11357. The U.S. Government retains for itself, and others acting on its behalf, a paid-up nonexclusive, irrevocable worldwide license in said article to reproduce, prepare derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the Government.

References

Conzelmann, G., M. North, G. Boyd, V. Koritarov, C. Macal, P.R. Thimmapuram, and T.D. Veselka, “Simulating strategic market behaviour using and agent-based modelling approach,” Proceedings of the Sixth European IAEE conference, Zurich, Switzerland, 2004.

Patterson, P., M. Singh, S. Plotkin, and J. Moore, “Multi-Path Transportation Futures Study: Results for Phase 1”, http://www1.eere.energy.gov/ba/pba/pdfs/multipath_ppt.pdf , March 2007.