Electric Vehicle Transportation Center

Electric Vehicle Energy Impacts

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Final Research Project Report

Electric Vehicle Energy Impacts

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1.0 Abstract

The objective of this research project was to evaluate the impacts of electric vehicles (EVs) and renewable wind and solar photovoltaic (PV) power generation on reducing petroleum imports and greenhouse gas emissions to Hawaii. In 2015, the state of Hawaii mandated fossil fuel electric power displacement by imposing Renewable Portfolio Standards (RPS) that will reach 100% renewable electricity generation by 2045. With small, remote and isolated island electricity grids, utilities in Hawaii face unprecedented technical and economic challenges to meet these goals with exceedingly high levels of intermittent wind and PV power generation. To meet these RPS goals, EVs become increasingly important in helping to balance intermittent power generation by providing a controllable load, and potentially an energy storage medium as well. In this work, high fidelity grid modeling and analysis of EV energy use and emissions was conducted for the Island of Oahu with the focus on the number of vehicles, charging strategies, and wind and PV penetration levels at present and in the future. Comparisons were made for different vehicle types and fuel mixes. Additionally, the state of EV integration into Hawaii's electric power grid was assessed and reported, including current challenges.

2.0 Research Results

The results and overview of electrified transportation in Hawaii were presented in two reports and three presentations, available on the EVTC and HNEI websites. Citations for these reports and presentations are as follows:

Reports

1. *The State of Electric Vehicles in Hawaii*, K. McKenzie, Hawaii Natural Energy Institute, University of Hawaii, March 2015; HNEI-05-15.
2. *The State of Electric Vehicles In Hawaii: 2016 Update*, K. McKenzie, Hawaii Natural Energy Institute, University of Hawaii, July 2016; HI-09-16.

Presentations

1. *Electric Vehicle Transportation and Power Grid Integration*, K. McKenzie, Hawaii Natural Energy Institute, Presented at Women in Renewable Energy, January 27, 2016.

2. *Electric Vehicle Transportation and Power Grid Integration*, K. McKenzie, Hawaii Natural Energy Institute, Presented at Engineers and Architects of Hawaii, February 26, 2016.
3. *Interaction of EVs In a High Renewables Island Grid*, K. McKenzie, Hawaii Natural Energy Institute, Presented at IEEE Transportation Electrification Conference and Expo (iTEC), Dearborn Michigan, June 29, 2016.

In addition, a technical panel with moderator was organized in collaboration with UCF's EVTC faculty for the 2016 IEEE Transportation Electrification Conference and Expo (iTEC) held in Dearborn, MI on June 27-29, 2016.

A summary of the above reported results and the modeling and analysis efforts follow.

2.1 Background

The electric power generation for the state of Hawaii is unique within the U.S. because most of the power generation comes from petroleum resources (68% in 2014). In addition, Hawaii has mandated that its fossil fuel electric power be displaced by imposing Renewable Portfolio Standards (RPS) that will reach 100% renewable electricity power generation by 2045. Meeting the RPS poses a challenge as most of the remaining gains in renewable power generation must come from wind and solar photovoltaics (PV), particularly on Maui and on Oahu, where most of the population resides. To maintain a stable power grid, second-by-second control of supply and demand must be precisely maintained at all times. However, existing electric power grids were designed using controllable, large scale power generation, such as from oil or gas-fired plants. However, wind and solar resources are intermittent, with fast fluctuations that can cause grid problems when these sources suddenly produce more or less power than is required to maintain supply and demand stability of the grid system.

Additionally, exceptionally high levels of solar resources in Hawaii (as in California) are causing an excess of power generation at midday, then solar energy drops off just as the demand for electricity typically ramps up in the late afternoon and early evening. When more power is produced than needed, the excess needs to be stored for later use or the excess wind and PV production must be reduced or eliminated. This process is referred to as curtailment. Controlled charging of EVs can be used to make use of this excess power.

Conversely, when wind or solar power generation suddenly declines, the load on the power grid must be rapidly reduced. This can be achieved by reducing EV charging (using demand response). Alternatively, to replace the rapid power decline from wind or solar resources, another power source must ramp up very quickly. In the future, EVs can potentially provide this fast response from energy stored in the EV battery using what is called vehicle-to-grid or V2G.

2.2 Modeling Results

In this work, grid-connected EVs were explored for their potential to take up the curtailed energy when wind and solar resources exceeded the maximum that can be absorbed into the electricity grid system. The Hawaii Natural Energy Institute (HNEI) and General Electric Energy Consulting (GE) conducted high fidelity dispatch modeling of the planned 2015 Oahu electricity grid system, ("Oahu Electric Vehicle Charging Study", 2013[1]). Future scenarios with high levels of wind and solar PV energy were modeled before and after large EV charging loads were added to the grid. In order to have meaningful results, long-term EV adoption levels (forecast out to 2040 and 2045) were used.

Before EVs were added, utility grid base cases were modeled. For Oahu, the peak load is 1200 MW. Modelling was done to show the effects of 600 MW to 1000 MW of combined wind and PV capacity. The results for this analysis showed that 10 to 23% of the combined wind and solar energy would need to be curtailed. When the wind drops and solar resources are diminished (such as from cloud cover or at night), petroleum power generation is increased on Oahu to supply the Island's power needs, including power needed to charge EVs.

Future scenarios were then modeled to evaluate the effects of using EVs to replace 10 to 30% of light-duty passenger vehicles currently on Oahu. The additional petroleum needed for electricity generation was quantified. Practical charging profiles analogous to a proposed utility time of use program were modeled, along with theoretically perfect EV charging, where EV charging was synchronized with wind and solar curtailment on an hourly basis each day. These results found that day-to-day variations in total wind and solar PV curtailment reduced the effectiveness of controlled EV charging in capturing curtailed energy. At best, assuming all EVs followed this theoretical, perfect charging profile, 53% of the available curtailed energy was captured. If constant charging is assumed, or a typical time of use controlled charging profile such as 70% of charging at night and 30% during the day, then only18 to 46% of the curtailed energy was captured[2]. The remainder of the power to charge the EV fleet must be provided from petroleum used to generate electricity.

With results from the petroleum fuel used to generate electricity in these modeled scenarios, EV electrical use and the resulting emissions were analyzed based on a battery-only powered passenger vehicle that consumes 34 kWh/100 mile[3] and travels 11,000 miles per year on average[4]. Results are applicable and can be scaled to Plug-in Hybrid Vehicles (PHEVs) running on a combination of electricity and gasoline. A factor of 2.7 can be used to multiply the number of EVs to determine a corresponding number of PHEVs. This is based on data from the U.S. Department of Energy for a representative EV with 24 kWh of battery capacity, and a representative PHEV with 4.4 kWh of battery capacity with average distance traveled on the battery versus gasoline. Comparisons of EVs were also made to light duty gasoline vehicles (achieving an average of 21.4 miles per gallon[5]), as well as highly efficient hybrid vehicles run entirely on gasoline (achieving 50 MPG).

This study focused on the additional petroleum used to generate electricity when an additional load from a large number of EVs is added to the power grid. Petroleum use was quantified in the HNEI-GE modeling study, where the goal in Hawaii is to reduce the amount of oil burned for power by replacing oil with wind and solar energy (along with other renewables). EVs petroleum use was compared to gasoline-powered vehicles by considering the energy equivalent of a gallon of gasoline (in miles per gallon equivalent or MPGe)[6]. Results ranged from approximately 45 to 57 MPGe. As EVs consume more renewables the amount of oil burned to charge EV batteries decreases and the EVs MPGe increases (where gallon equivalent refers to the energy content of petroleum consumed to generate electricity).

Results from the study showed that controlled EV charging can use surplus renewable energy from wind and solar PV. However when considering petroleum consumption for electricity in the modeled scenarios, it took a high level of curtailed energy (23%) for EV MPGe to exceed that of a 50 MPG gasoline-powered hybrid vehicle.

In the future, the role EVs will play in balancing intermittent wind and solar resources on Oahu's power grids will become more critical as Hawaii progresses towards its RPS goal of 100% renewable electricity by 2045. Toward that end, further modeling scenarios were conducted to reach interim goals with 20% wind and solar energy on Oahu, based on the utility's original Power Supply Improvement Plan (PSIP) for 2020. (The RPS goal for 2020 has since been increased to 30% renewables.) In addition to improving grid operations, additional solar power was also added to the PSIP scenarios to reflect the rapid increase in PV installations, increasing renewables up to 24%[7]. To assess the impact of increased demand for electricity caused by EV charging, additional loads of 5% and 10% were added. This represents replacing approximately 10 and 20% of the forecast number of cars on Oahu with 122,000 and 244,000 EVs respectively, in line with EV adoption levels forecast[8] out to 2040 to 2045. Based on the grid modeling results for these PSIP scenarios, EV mileage in these scenarios ranged from 40 to 45 MPGe.

2.3 Comparison of EVs to Other Passenger Vehicles

Although EVs can be more efficient than comparable conventional gasoline-powered vehicles, additional load on the power grid on Oahu results in additional power generation from petroleum. Since EVs can be incentivized to replace gasoline vehicles, the benefit of an additional load on the power grid due to charging a large number of EVs was calculated, along with the impact on reducing curtailed wind and solar energy.

Comparisons were made to fueling the same number of light duty gasoline-powered passenger vehicles, (getting an average of 23.4 MPG[9]). For each 23.4 MPG vehicle replaced with an EV in these scenarios, the net petroleum savings ranged from 197 to 224 gallons of gasoline per year. If Oahu's penetration of wind and solar energy do not increase beyond these modeled levels, this would save up to roughly 18% of the total gasoline currently used on Oahu (all imported). If we assume Oahu's entire passenger vehicle fleet gets an average of 23.4 MPG, to achieve the same fuel savings would require an overall improvement of approximately 2 to 5 MPG for every passenger vehicle. Looking at this in terms of Oahu's current gasoline use, if 20% of the current passenger vehicles were replaced with EVs achieving 45 MPGe, approximately 39 million gallons of gasoline would be saved each year. Note that electricity for fuel is a slightly higher cost or the same as gasoline in Hawaii (according to the DOE's price comparison tool, eGallon; https://energy.gov/maps/egallon).

However, under these future scenarios the EVs at 40 to 45 MPGe are surpassed by 50 MPG gasoline-powered hybrid vehicles. Compared with a 50 MPG hybrid, each EV in the modeled scenarios range from using an additional 6 to 13 gallons of gasoline per year. As larger amounts of wind and solar are added to the grid, it is reasonable to expect the EV fuel savings to become comparable to and eventually surpass 50 MPG hybrids. However, estimating future EV mileage and emissions is dependent on the power grid operation and fuel mix, along with EV charging profiles.

As expected, the 40 to 45 MPGe EVs in this modeling study have lower carbon dioxide (CO_2) emissions as compared with similar gasoline vehicles running on E10. CO_2 emission savings ranged from 528 up to 1,048 pounds of CO_2 per year for the 10 or 20% of the forecast number of cars on Oahu replaced with EVs (122,000 and 244,000 EVs respectively).

2.4 Future Modelling

Because of the importance to understanding Hawaii's path moving toward the mandated interim RPS goals which are now 30% by 2020, 40% by 2030, 70% by 2040 and 100% by 2045, continuing grid modeling is being done using other funding sources, for the increased renewable energy levels. In addition, EV charging and the use of EVs for energy storage is being analyzed as a means of improving power quality and grid stability for high levels of intermittent resources.

HNEI and GE modeling of future scenarios on Oahu with advanced grid operations has shown that above 40% penetration of PV power, approximately 90% of any additional PV would be curtailed. The modeling results also show that small changes in inputs or scenario assumptions can have a significant effect on results. For example, results with 50% wind and solar energy scenarios lead to significant curtailment of approximately 12% to 27%, depending on the mix of resources and changes to the utility's operations. Future steps will include the addition of EV loads and investigation of energy storage to provide services to the power grid which can offset costs to EV owners as well as the utility. With increasingly cleaner sources of power generation, EVs offer progressively more energy and emission savings over average gasoline vehicles. For Hawaii, these changes to ground transportation would have a significant effect on reducing petroleum imports, improving energy security and economic stability.

As illustrated by this project, electricity and transportation planning must go hand in hand for a smooth transition into the future. HNEI and GE's modeling are a cooperative effort with monthly Steering Committee meetings as well as informational meetings and presentations involving the utility, state and other stakeholders. Additionally, EVTC reports and presentations continue to provide guidance for planning purposes, including consideration in the direction of the HNEI-GE modeling, utility and state planning. During this Hawaii 2017 legislative session, proposed bills have received wide support to match the 100% clean electricity by 2045 goal with 100% clean transportation. In addition, the Hawaii DOT is now leading a Sustainable Transportation forum including other state agencies and other stakeholders for planning and coordination purposes.

3.0 Conclusions

This work has presented high fidelity grid modeling and analysis of EV energy use for the Island of Oahu. The work focused on the number of vehicles, charging strategies, and wind and PV penetration levels at present and in the future. Comparisons were made for different vehicle types and fuel mixes. Additionally, the state of EV integration into Hawaii's electric power grid was assessed and reported. The results show that at the current time more petroleum can be saved and emissions reduced by replacing most gasoline cars with 50 MPG hybrids rather than with EVs. However, with the rapidly increasing levels of renewable energy generated from wind and solar resources, EVs are poised to surpass gasoline-powered hybrids in Hawaii's future. As demonstrated by this modeling and analysis study, EVs become increasingly important in balancing the intermittent nature of wind and PV power generation. For Hawaii, EVs hold the promise of helping to reduce petroleum imports and emissions for both transportation and electricity.

4.0 Impacts/Benefits

Benefits of modeling and analysis efforts have shown the need for understanding of the integration of EVs to balance renewable energy integration on the power grid. This work also shows the impact of replacing gasoline vehicles on the overall fuel use and emissions considering both transportation and power generation needs. This Hawaii-focused effort has direct application to isolated grids, micro-grids and more universal application to larger grids at the distribution or circuit level. Knowledge gained in Hawaii will play a role in helping to shape the electrification of transportation in other regions of the U.S., particularly as it relates to integration of high levels of renewables and energy storage on the power grid.

5.0 References

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3. U. S. Department of Energy, mid-size EV (2011 Nissan Leaf), kilowatt-hours of electricity to travel 100 miles, http://www.fueleconomy.gov/

4. Market Trends Pacific for HNEI; annual miles traveled rounded up to 11,000 and: U.S. Department of Transportation (U.S. DOT), 2011 annual mileage rounded down to 11,000

5. U.S.DOT, Office of Highway Policy Information, average of 21.4 MPG for light duty vehicles, (2011)

6. Hawaii Natural Energy Institute, University of Hawaii at Manoa, Strategic Use of Electric Vehicle Charging to Reduce Renewable Energy Curtailment on Oahu, (September 2013)

7. HNEI and GE, Executive Summary: Hawaii RPS Roadmap Study, presentation to the Hawaii State Capitol, (January 2014)

8. University of Hawaii, Economic Research Organization for HNEI, M. Coffman, P. Bernstein, S. Wee, http://evtc.fsec.ucf.edu/publications/documents/HNEI-04-15.pdf, (April, 2015)

9. U.S. DOT, Federal Highway Administration, Highway Statistics (Washington, DC: Annual Issues), light duty passenger vehicle average fuel efficiency in 2013 from table VM-1, http://www.fhwa.dot.gov/policyinformation/statistics.cfm (2013)