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The effectiveness of plug-in hybrid electric vehicles and renewable power in support of holistic environmental goals: Part 2 – Design and operation implications for load-balancing resources on the electric grid

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HIGHLIGHTS

- PHEV integration counteracts the impacts of renewables on the grid to an extent.
- PHEV benefit for grid limited by load size and driver flexibility constraints.
- Smart PHEV charging services can provide cost savings for the electric grid.
- Electricity cost savings must be weighed against PHEV infrastructure cost.
- Smart charging is essential for PHEV benefits on the electric grid to be realized.

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ABSTRACT

A study has been performed that analyzes the effectiveness of utilizing plug-in vehicles to meet holistic environmental goals across the combined electricity and transportation sectors. In this study, plug-in hybrid electric vehicle (PHEV) penetration levels are varied from 0 to 60% and base renewable penetration levels are varied from 10 to 63%. The first part focused on the effect of installing plug-in hybrid electric vehicles on the environmental performance of the combined electricity and transportation sectors. The second part addresses impacts on the design and operation of load-balancing resources on the electric grid associated with fleet capacity factor, peaking and load-following generator capacity, efficiency, ramp rates, start-up events and the levelized cost of electricity. PHEVs using smart charging are found to counteract many of the disruptive impacts of intermittent renewable power on balancing generators for a wide range of renewable penetration levels, only becoming limited at high renewable penetration levels due to lack of flexibility and finite load size. This study highlights synergy between sustainability measures in the electric and transportation sectors and the importance of communicative dispatch of these vehicles.

1. Introduction and background

1.1. Introduction

The previous part of this study evaluated the effectiveness of plug-in hybrid electric vehicles (PHEVs) with smart charging on aiding the combined electricity and transportation sectors in improving system progress towards meeting aggregate sustainability goals. The use of PHEVs with smart charging was able to increase renewable energy utilization in both sectors as well decrease CO_2 emissions and fuel usage. Fully realizing these benefits, however, required taking advantage of synergies between PHEV and renewable power generation deployment. Without taking into account these synergies, the extent of the benefits was reduced.

Examining the aggregated emissions and energy usage metrics alone only provides a part of the picture regarding the interactions and impacts associated with electricity and transportation sector integration. The use of PHEVs with smart charging do not only affect the annual emissions and energy usage patterns of the

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electric grid, the character of their load profile also affects the design and operation of load balancing resources on the system. Balancing generators on the grid have many constraints on how dynamically these units can operate, including but not limited to part-load turn down limits, ramping limits, and start-up event limits. Changes in the character of the net load profile that these units must meet also have implications for the efficiency, capacity factor, distribution of load-following and peaking capacity of the balancing generator fleet and the levelized cost of electricity from this system. This part of the study investigates the impact of the PHEV charging load on the operation of load balancing resources with increased renewable penetration levels on the electric grid.

The impact of introducing intermittent renewable generation without alternative transportation integration has been studied due to initiatives in the electricity sector to increase the share of renewable power generation.

Eichman [1,2] investigated the effect of installing increased levels of wind and solar power on the operation of balancing generators using the HiGRID tool. These studies found that intermittent renewable generation can have significant impacts on balancing generators in the absence of complementary technologies. Balancing power plants were required to operate at lower part-load levels, resulting in balancing power plant efficiency decreases of up to 2.8% at the 43% renewable penetration level when installing a 50%/50% capacity mix of wind and solar power. Lower part-load operation also implied increased criteria pollutant emissions. The number of balancing power plant start-up events were found to increase up to a certain point, after which a decrease would take place due to excessive amounts of renewable curtailment causing balancing generators to remain offline for long periods of time.

A study by the California Independent System Operator (CAISO) examined the effect of increasing intermittent renewable power on the required ramp rates of balancing generators for renewable penetration levels of 12%, 20%, and 33% [3]. This analysis found that the load-following fleet ramp rate up and down capability needed to be increased slightly from the 12% to the 20% renewable penetration level, but needed to be significantly increased from the 20% to the 33% renewable penetration level. This implies an exponential increase pattern with renewable penetration level. Eichman [1] also noted increases in the balancing generator fleet ramp rates with increased intermittent renewable generation up to a point, after which decreases due to excessive renewable curtailment occurred.

An examination of the costs and wear on balancing generators associated with increased intermittent renewable generation was investigated by Kumar [4]. This study found that with current technologies, increased ramp rates and number of start-up events can cause damage to power plant equipment and shorten power plant component lifetimes. Aging power plants that were designed around base load operation were most vulnerable to damage.

Effects on the composition of the balancing power plant fleet have also been examined. Due to increased dynamics from renewable generation, Eichman [4] found that an increased reliance on peaking generation occurred with increased renewable penetration level on both a capacity and an energy basis. A study by Tarroja [5] also found that the capacity percentage of non-renewable generator capacity that operates for longer than 1 week was found to drop significantly with increased renewable penetration level. Additionally, a study for the Southwest Power Pool projected that even at present wind penetration levels in their respective region, approximately one-third to one-half of base-load coal plants will not be needed to provide power during minimum net load hours [6].

Effects of increasing the renewable penetration level on the electric grid on the levelized cost of electricity have also been examined in the absence of complementary technologies. Eichman [1,4] found that increased intermittent renewable penetration increases the levelized cost of electricity linearly at first, and then exponentially as renewable curtailment becomes excessive. This behavior included cost factors such as renewable installation costs, shifting in fuel mix and degradation due to increased operational flexibility with current technologies.

Overall, many studies have identified that the variable nature of wind and solar power increases the dynamics of the net load profile and therefore the strain on balancing generators [7,8]. These studies imply the need for complementary technologies to mitigate these issues. Very few studies, however, have been conducted to date that examine the potential for the use of PHEVs as a complementary technology in obtaining a synergy with the electric grid by providing benefits for the operation of load-balancing resources.

Dallinger [9] examined the role of grid-connected vehicles in improving the integration of renewable energy sources in California and Germany by examining the impact on the net load profile. This study compared the regional differences between these systems, as well as the effect of different charging strategies: last trip charging, time of use tariff charging, and demand side management charging. The study found that last trip charging resulted in a reduced electric driving share, increased net load ramp rates, and contributed only a small amount towards balancing renewable resources. Time-of-use tariff charging was found to balance renewable power generation only if the net load profile was regular and periodic. With non-periodic renewable generation, time-of-use tariff charging did not provide enough flexibility to gain benefits. Demand-side management charging was found to reduce net load ramp rates and was able to provide the most contribution towards managing intermittent renewable resources. This strategy was found to be more effective in California compared to Germany due to the characteristics of the load and renewable generation in that region.

Wang [10] investigated the effects of PHEVs on power systems with demand response and wind power. The net load profile was used to evaluate the impacts on the Illinois power system in 2020. It was discovered that by acting to level the load demand, system costs can be decreased significantly, and further decreased by using demand response measures in conjunction. Druitt [11] examined the use of EVs to balance the electric load demand with increased wind penetration levels, also focusing on the effects on the net load profile and pricing signals. It was discovered that EVs were well suited for the uptake of intermittent renewable power in the UK and improved load-following conditions in both demand management and vehicle-to-grid operation modes.

Other studies have focused on characterizing the profile of the PHEV charging load in relation to the stationary load demand. Zhang [12] examined the use of PHEVs with different all-electric-ranges as a function of charging location and charging strategy. It was discovered that immediate home charging exacerbates the grid load peak and delayed charging acted to smooth the load profile on average. Charging at non-home locations increased loads during the daytime. Bashash [13] examined the profile of the PHEV load using a charging strategy that focused on maximizing vehicle battery life. This introduced a PHEV load peak in the early-mid morning hours. Weiller [14] examined the characteristics of the PHEV charging load as a function of charging location options. Charging at home only caused increases in the net load demand during the late afternoon and early evening hours, whereas charging at home, work, and commercial places tended to smooth out the PHEV profile. Other studies have provided into aspects of this area as well [1,15–17].

Overall, however, few studies focus on the effect of PHEV charging on the operation of balancing generators on the electric