

A Survey of PEV Impacts on Electric Utilities

Ryan Liu, *Student*¹; Luther Dow, *Life Member IEEE*²; Edwin Liu, *Fellow IEEE*²

Abstract: For the past few years, plug-in electric vehicle (PEV) technology development has gained immense popularity. Recent studies show that if PEVs displaced half of all vehicles on the road, they would require only an 8% increase in electricity generation. Results similar to this help encourage the continuing development of PEVs. Despite this small increase in generation, uncontrolled charging, especially during on-peak summer hours, could overload the current power grid. This paper provides a narrative literature survey of the development and impact of PEVs. Subjects cover PEV industry trends, charge and discharge scenarios, and impacts on distribution systems. Some concluding remarks are summarized.

Keywords: smart grid, plug-in electric vehicle, demand response, controlled and uncontrolled charges, electrification of transportation

I. INTRODUCTION

Electrification of transportation has become an important industry trend supported by the interest of energy independency. For the past few years, plug-in electric vehicle (PEV) technology development has gained immense popularity because of the PEV's ability to reduce greenhouse gases (GHGs) and its ability to alleviate the effects of rising gasoline prices on the consumer. Recent analysis indicates that significant portions of the U.S. gasoline-operated vehicle fleet could be fueled with the available electric capacity. In fact, about 84% of the total energy needed to operate all of the cars, pickup trucks, and SUVs in the U.S. could be supported using generation capacity currently available [1]. The National Renewable Energy Laboratory (NREL) concluded that large-scale deployment of PEVs will have limited, if any, negative impacts on the electric power generation requirements [2]. Recent studies showed that if PEVs displaced half of all vehicles on the road by year 2050, they would require only an 8% increase in electricity generation (4% increases in capacity) [3]. Results such as these have encouraged the continuing development of PEVs.

Opinions on the effects of PEVs on the power grid, however, vary. Across the California system, CPUC staff analysis finds that in an extreme, worst-case, uncontrolled scenario, assuming that three million vehicles charge simultaneously, 5,400 MW are needed in additional connected load capacity if the vehicles charge at 120V outlets, or 19,800 MW for 220V outlets. California's power grid capacity would have difficulty meeting this additional load, if it occurred on-peak during the summer. Although this is a worst case scenario, a 2008 Oak Ridge National Laboratory (ORNL) study pointed out that consumer behavior and charge timing is not predictable. Worst cases still need to be addressed; consumers may elect to charge when convenient, rather than when utilities would prefer. On the other hand, if the charging of PEVs occurred primarily off-peak, they could even improve the load curve for electric utilities [4]. Hence, in order to optimize the usage of available generation capacity to support possible high penetration of PEV, its impacts on power grid should be examined including different charging scenarios and technologies.

This paper provides a narrative literature survey of the development and impact of PEVs. The paper first gives information about expected PEV penetration rates in Section II, then discusses charge/discharge scenarios in Section III. Section IV provides the crux of the paper, discussing the various impacts of PEVs on power distribution. Concluding remarks are summarized in Section V and references can be found in Section VI.

It should be noted that throughout this paper, PEV is used as a general term that may include plug-in hybrid electric vehicles (PHEVs) and electric vehicles (EVs).

II. INDUSTRY TRENDS

PEV market penetration rate estimations and statistics are important to understand the market trends and are also used to more accurately assess and predict the potential impact PEVs have on the U.S. energy sector. This section of the paper provides information regarding present and future penetration rates. This section does not provide analysis, but rather presents information that is available in the cited literatures.

1. Ryan Liu is a student at University of California, Berkeley.

2. Luther Dow and Edwin Liu are with Quanta Technology, LLC, in Oakland, California.

Penetration Rates for the United States

The two following graphs show the conglomerated PEV penetration rates and sales from a variety of sources [3,5,6,7,8]. The numbers in the legend refer to the different source citations found in Section VI.

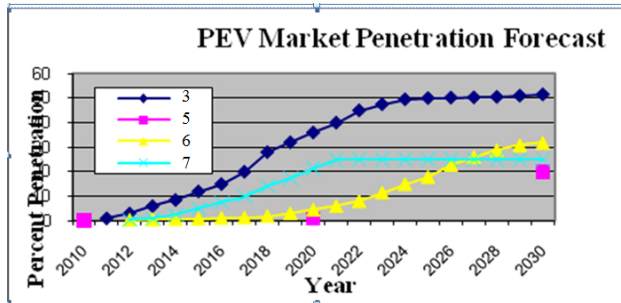


Figure 1 PEV Market Penetration

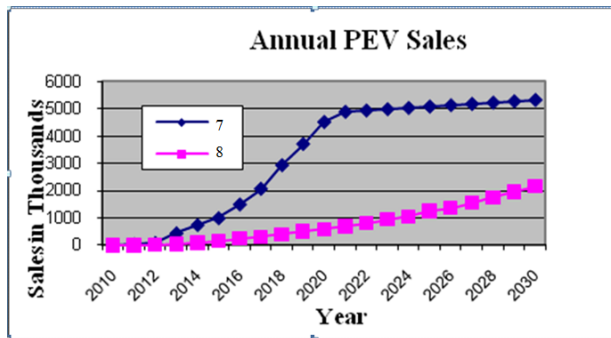


Figure 2 PEV Sales

Penetration Rates for Specific Regions

The penetration projections in NERC regions as well as Alaska and Hawaii were reported in [7]. Each region's share of total vehicles in 2004 and projected number of PEVs in 2020 and 2030 are summarized in the following table.

Region	Percentage of total vehicles registered (2004)	Projected number of PHEVs on the road (millions)	
		2020	2030
1 ECAR	12.4%	2.44	6.27
2 ERCOT	7.2%	1.41	3.62
3 MAAC	9.0%	1.77	4.54
4 MAIN	9.4%	1.84	4.73
5 MAPP	3.6%	0.71	1.81
6 NPCC-NY	4.8%	0.94	2.42
7 NPCC-NE	5.2%	1.03	2.64
8 FRCC	6.1%	1.20	3.10

Region	Percentage of total vehicles registered (2004)	Projected number of PHEVs on the road (millions)	
		2020	2030
9 SERC	17.3%	3.38	8.70
10 SPP	2.2%	0.44	1.13
11 WECC-NW	5.3%	1.04	2.67
12 WECC-RMP/ANM	3.5%	0.69	1.78
13 WECC-CA	13.1%	2.57	6.63
14 Alaska and Hawaii	0.7%	0.14	0.35
Totals	100.0%	19.58	50.39

Table 1. Penetration in NERC regions, Alaska, Hawaii

There are also some specific region studies available. For example, California ISO used three different PEV penetration scenarios for its planning analysis. One forecast assumes that PEVs sales grow 20% annually. Under this scenario, the total PEV in California ISO region will reach 1 million in 15 years. The second scenario is a transition to 100% market share over 25 years. The third assumes an aggressive transition to 100% market share in 12 years, or about two product cycles. That leads to almost 17 million PEVs in California ISO region.

In addition, a recent report showed that PEV penetrations may reach as high as 16% of total vehicles in SCE's service territory by 2020.

III. CHARGE AND DISCHARGE

PEV Charge Characteristics and Management

The SAE J1772 identifies three levels of charging based on voltage and power levels, as shown in Table 2.

PHEV CHARGING MODEL CHARACTERISTICS

Type	Power Level
Level 1: 120 VAC	1.2 – 2.0 kW
Level 2 (low): 208-240 VAC	2.8 - 3.8 kW
Level 2: (high): 208-240 VAC	6 – 15 kW
Level 3: 208-240 VAC	>15 KW-96KW
Level 3: DC Charging: 600VDC	>15KW-240KW

Table 2. SAE J1772-defined charging levels

The Table 3 below shows where charging stations can be located by type of station [9].

	Charging Station Type		
	Level 1	Level 2	Level 3
Residential			
Single family houses.....	X		X
Multi-family units.....	X		X
Commercial/Employment Centers			
Private (Office complexes, business campuses).....	X		X
Commercial/Retail (fleet and delivery services).....	X		X
Public access (airports, hotels, grocery stores, hospitals, shopping malls and entertainment).....	X	X	X
Government, universities, and municipal facilities.....	X		X
Transit hubs.....		X	X
Fueling stations.....		X	X
Public			
Parking structures/lots.....	X	X	X
Street.....		X	X
Interstate and highways.....			X

Table C4: Location of charging stations by type

Table 3 Charging Scenarios

In general PEV battery capacity can range from 2kW to 17kW which is at the same level of one typical residential household power usages. While the charge time is usually several hours, the typical daily energy

requirement of PEV may be on the order of 5 to 40 kWh.

The power demand of charging PEVs is a function of the voltage and current of the charger. The capacity of the battery then determines the length of charging time. For example, a 120V AC charger, depending on the battery pack sizes, charging time can range from 3 to 8 hours. Larger battery packs (for longer range) would require higher voltage or current to reduce the charging time.

The following six charging cases represent scenarios covering the most likely range of charging strategies to be expected [10].

- Case 1: 120V charging at home
- Case 2: 120V charging at home and work
- Case 3: 120V charging at home delayed until after 10pm
- Case 4: 50/50 120V/240V charging at home
- Case 5: 50/50 120-V/240V charging at home and work
- Case 6: 50/50 120-V/240V charging at home delayed until after 10pm

Base loads are plotted below with two different PHEV penetration levels and the 6 different charging scenarios explained previously from data gathered from Franklin PUD in Washington.

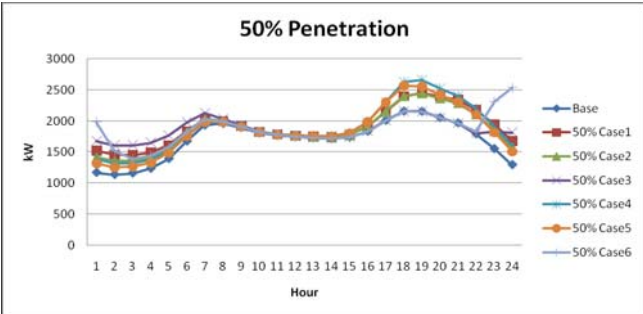


Figure 3 Load Curves of 50% Penetration

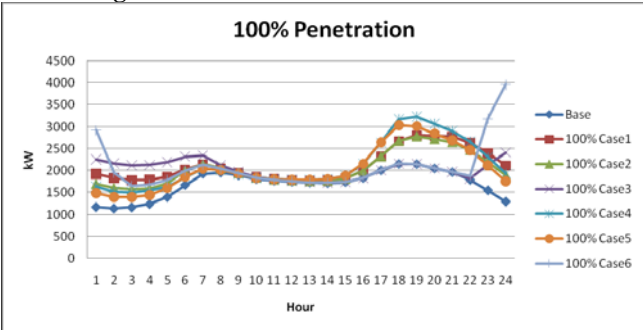


Figure 4 Load Curves of 100% Penetration

Below are several recently reported research results related to charging station designs and management. In [11], a single AC/DC conversion and DC distribution to DC/DC charging units are proposed. In addition, it also proposes to connect an ultracapacitor energy storage to the DC bus to supply power when the demand exceeds the average that can be provided from the grid. Infrastructure design issues related to parking lot charging were reviewed in [12]. Its simulation results showed that a 230 KVA transformer is needed for every 50 parking spaces. In [13], the system architecture needed to integrate PEVs into the grid operation was studied, providing suggested parameters that need to be measured.

Charging PEVs can be either “controlled” or “uncontrolled.” Based on studies in [7] [14], people may most often charge their PEVs as soon as they arrive home, which may cause a daily charging peak around 6pm-8pm. In order to mitigate the impacts on the grid, certain strategies need to be implemented to manage charging behavior. Charge management methods can be summarized as follows.

Opportunity	Near Term	Long Term
Tariff/TOU Rates	Tiered TOU Rates	Real Time Pricing (RTP)
Smart Charging	User/Vehicle Controlled Charging	Critical Peak Pricing (CPP)
Vehicle to Grid		Utility Controlled Charging
		Utility Controlled-2 way power flow

An effective way to manage the PEV charges is through the use of residential Time-of-Use (TOU) tariffs. Each PEV TOU tariff is either for a bundled household and vehicle load, or just a segregated vehicle load. This segregated vehicle load rate requires separate metering. A TOU schedule offers reduced rates per kWh on a pro-rated basis for off-peak charging, with incremental rate increases for vehicle charging during partial peak and on peak demand times. Many utilities now offer TOU rates to customers [15]. Demand response (DR) is another potential dynamic benefit related to PEV load. With DR, the utility may be able to interrupt PEV demand during high demand hours to mitigate PEV load impacts [15].

Another type of controlled charging can be grouped as “smart charging,” enabled by AMI and application software systems so that PEV outlets and household loads can be switched ON/OFF [16]. One form of smart charging is the stagger charge method. The PEV control unit monitors the distribution transformer load information and continuously compares it with a

pre-determined loading value. PEVs will be charged if the transformer load is less than the pre-determined loading value, i.e. original peak load. However, if the transformer loading is greater than the pre-determined loading value, charging PEVs will be delayed until the transformer loading falls below the threshold [16]. The household load control is somewhat similar to the stagger charge method because it implies that the non-critical loads can be shed or deferred when PEVs are being charged. In this household load control method, real-time electrical energy consumptions of all household loads must be monitored [16].

Vehicle-to-Grid (V2G) Discharge

Just as plug-ins seem a logical next step for hybrid-electric vehicles, making the plug-in bi-directional so that homes or utilities can draw power back from the plug-in vehicle batteries when needed is a natural step beyond that. This vehicle-to-grid (V2G) discharge system will allow homeowners or utilities to take greater advantage of the investment in vehicle batteries, thereby reducing vehicle ownership cost. One scenario of V2G has vehicle owners avoiding peak time charges by drawing on their own electrical storage system at peak times (while recharging at low-rate off-peak times). V2G batteries become distributed storage systems for the electrical grid and would help pay back the cost of having these added batteries in PEVs [4]. The distributed storage would also make the electric grid more stable, secure, and resilient by providing services such as frequency regulation and spinning reserve as well as backup capacity within the distribution system. Distributed electrical storage provided by V2G systems could allow greater penetration of wind and solar resources.

A practical demonstration of V2G scenarios was reported in [17], which provided real-time frequency regulation from an electric car. The study showed that V2G can provide distribution system support when there is a concentration of parked V2G cars (batteries), along overload elements in the distribution system. The results also showed that V2G, in addition to providing valuable grid services, could prove to be a prominent application in the global transition to the emerging green and sustainable energy economy [17].

V2G is an ideal scenario that enables PEVs to contribute to power grid operations. Nevertheless, implementing any effective V2G methods requires supporting infrastructure, interface standards, tariffs, market rules, etc. It presents challenges across many industries.

IV. IMPACTS ON DISTRIBUTION SYSTEMS

This section discusses some specific impacts PEVs have on the power distribution system.

Phase Imbalance

A study at Northumbria University, UK, reports that with fewer active chargers (e.g. lower percentage of EVs being charged), the diversity was lower, resulting in a larger variation in the current imbalance. However, the lower total load reduced the voltage imbalance, which therefore remained within limits. Conversely, when the number of chargers switched on was high, the diversity was high, resulting in a lower average current imbalance [18]. As a result of these two trends, the voltage imbalances remained within limits over a wide range of tested conditions

Power Quality Issues

PEVs charge by drawing low voltage AC power and converting it to DC. This process involves rectifying the AC signal and running the rectified signal through a DC/DC converter. Both of these processes produce harmonic distortion in the distribution system [19].

The proliferation of loads containing nonlinear elements such as inverters and battery chargers, has led to a significant increase in voltage distortion and current harmonics on power distribution networks. These harmonics cause problems on the power system, including excessive neutral current and transformer hot spots. Chargers for storage batteries form a significant class of harmonic-producing loads, and particularly as electric vehicles attain technical and commercial success, these chargers will become widespread in the residential distribution network. The harmful effects of harmonics have been reported [20].

The partial result of the application of new designs is the reduction of the harmonic distortion and the improvement of the power factor. A recently published report indicate actual current total harmonic distortion (THD) values at the beginning of charging between 2.36% and 5.26%, reaching up to 28% at the end of charging. Some researchers, however, claim lower THD values ranging between 1 and 2%, with a power factor very close to unity [21]. There is no general agreement among the THD values generated by different battery chargers. Some manufacturers and researchers claim of having designs with extremely low THD, while others consider the charger as highly contaminating load, with

suggested average THD value of about 30%. Measurements carried out on commercial chargers showed THD values as high as 60 to 70% [21].

Since the introduction of the first industrial and commercial EV applications nearly 20 years ago, current harmonics of chargers connected to the same phase were essentially additive. This is because the charging process in all EV chargers (all having similar characteristics) start at practically the same time in order to use the cheapest energy—eventually disconnecting during peak hours. Also, the state-of-charge in different EVs is very similar due to the precisely planned maximum load utilization [21]. The net effect of a population of EV chargers today is not merely the numerical sum of the THDs, which involves both the magnitudes and phase angles of individual harmonic components. Harmonic phase cancellation effect will take place especially for higher harmonic orders.

Transformer Degradation and Failure

Under certain charging voltage and timing assumptions, an average of less than one PHEV per household could increase asset overloading on the neighborhood transformer. A commonly used 25 kilovolt-ampere (kVA) neighborhood transformer serves the typical household load for five to seven homes. Level 2 charging (for example, at 6.6 kW) for a BEV can increase the load served by the transformer by the equivalent of an additional household load; a PHEV charging at 120V (1.4 kW) is the equivalent of a third of a household load [22].

The following shows Pacific Northwest National Laboratory (PNNL) results from a transformer load study. In this analysis, the PHEV load increases failure rate by an additional .02% per year [23].



Figure 5 Transformer Failure

The distribution transformer is designed for specific load carrying capability based on typical load consumption patterns. When PHEVs are deployed, the normal electric power demand pattern will change. The power system may or may not be capable of handling the new pattern and level of demand [24].

The addition of a PHEV load can have a more significant impact on the individual distribution transformer than on the system as a whole. While exceeding normal ratings will not necessarily result in device failure, it does effectively reduce the operation lifespan of the transformer. As PEV charging will alter typical customer load profiles, additional evaluations addressing transformer “loss-of-life” as a function of PEV type and connection time are performed based on IEEE standard C57.91. How PEV loading can influence transformer lifespan is illustrated by the example case shown below in Table 4 [25].

# PEV	Aging per Year (% of Normal Lifespan)			
	120V 12A	120V 12A	240V 30A	240V 30A
	Peak	Off-peak	Peak	Off-Peak
0	0.60 %	0.60 %	0.60 %	0.60 %
1	1.05 %	0.64 %	1.72 %	0.84 %
2	1.99 %	0.71 %	9.16 %	2.75 %
3	3.99 %	0.83 %	69.02 %	20.22 %

Table 4 Transform Aging

The base case load shape for the 25kVA transformer is assumed to have a peak value of 90% of the transformer rating and a load factor of 44%. As additional PEVs are introduced the transformer’s equivalent load shape is altered by the PEV charge profile and connection time. The new load shape coupled with the assumed ambient temperature profile is then used to calculate the transformer insulation aging that occurs. For this example, the 120V off-peak charge represents a minimal reduction to the lifespan of the transformer. The reported percentages are based on the assumed normal insulation lifespan of 20.55 years when operating at rated load [25].

Numerous studies have found that harmonic distortion, increased temperature, harmonic distortion, penetration rate (number of vehicles per transformer), and charging characteristics decrease a transformer’s lifespan [25].

One study shows that adding the additional electric load demand to distribution transformers will have a measurable effect on the expected life of the distribution transformer. Specifically, if it is assumed that an average distribution transformer would operate for 150,000

hours (17.1 years), then the added impact of one PHEV decreases this expected lifetime to 132,015 hours (15.1 years). Similarly, the added impact of two PHEVs decreases it to 106,740 hours (12.2 years) and the added impact of three PHEVs decreases this expected lifetime to 84,390 hours (9.6 years) [24]. [19] shows that concentrated charging of electric vehicles will lead to an increase in transformer degradation. Figure 6 below plots the degradation of a given transformer as a function of the number of plug-in hybrids served. According to the study, these transformers typically serve 5-7 households. If a cluster of 5-7 households adopts 3 to 5 plug-in hybrids and charges them at 240 volts, transformer degradation increases precipitously. This scenario will be quite common because adoption of electric vehicles will be concentrated in certain neighborhoods and 240 volt charging will be prevalent (in fact, 240 volt charging will be required for LEAF owners) [19].

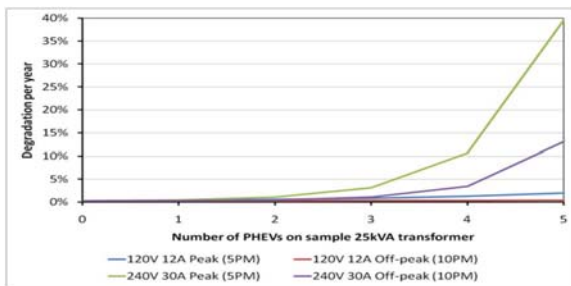


Figure 6 Transformer Degradation

Circuit Breaker and Fuse Blowout

There is some evidence that current harmonic distortion can affect the interruption capability of circuit breakers. The circuit breaker behavior during the interruption of high-level fault currents is not affected. Load distortion can result in higher di/dt at zero crossing, making the light overload interruption more difficult. Thermal behavior of circuit breaker is also affected, especially in such cases where the rms current value is used for overcurrent sensing, as in miniature circuit breakers (MCB) or molded case circuit breakers (MCCB). The effect of the highly contaminated harmonic current on the fuse behavior has two aspects—one is the thermal influence and the other is the dissimilar current distribution. The one aspect under consideration affects two fuse functions—the behavior in steady-state regime and the interruption of extremely light overcurrent values. The breaking capacity under short-circuit currents is not affected due to this type of failure, it usually produces currents without any harmonic contamination. The fuse is a device which mainly reacts

to the heat generated by the current through it. Its characteristic curves, based on rms values, are not affected by the harmonic content. The higher-rated current fuses are built with several parallel ribbons as fuse elements, between which the current distribution is strongly affected by skin and proximity effects. In order to solve the problem of dissimilar current distribution, derating factors based upon frequency have been proposed. The effect of harmonics on light overcurrent interruption is the extension of the arcing period, until the new zero crossing point. This delayed interruption will demand higher arc energy levels [21].

A U.S. Department of Energy study of the effects of PHEVs on Franklin PUD, PSE Distribution System, and Snohomish PUD infrastructure reports that the most common component found prone to failure from overloading was the protective fuse. Few papers discuss the probability and effects of fuse failures. This is because of their ease in repairs and the fact that their vulnerability can be mitigated by simply replacing them with a higher rated device. Fuses inadequate for the higher demand could be replaced with high rated ones at low cost; however, in most cases, these locations would require additional up-sizing of other line components at generally more significant cost [10].

V. CONCLUDING REMARKS

PEV development has gained immense popularity. Although its demand on overall power generation capacity may not be significant, the possible impacts on power delivery systems, especially the distribution system can be an issue if the charge is totally uncontrolled. Depending on the charging technologies and possible penetrations, impacts on power distribution system may include power quality, voltage, transformer life, etc. Mitigation strategies should be developed while promoting the PEV.

This survey can serve as a reference for researchers and engineers interested in investigating relevant subjects more extensively.

ACKNOWLEDGEMENT

The authors like to thank Dr. ML Chan and Professor Chan-nan Lu for their valuable discussion during the course of this review project. The project was a research project sponsored by Quanta Technology, Oakland, California.

VI. REFERENCES

1. M. Kintner-Meyer, K. Schneider, and R. Pratt, "Impacts Assessment of PHEV on Electric Utilities and Regional U.S. Power Grids, Part 1: Technical Analysis," PNNL SA-53700, November 2007 (http://energytech.pnl.gov/publications/pdf/PHEV_Feasibility_Analysis_Part1.pdf)
2. P. Denholm and W. Short, "An Evaluation of Utility System Impacts and Benefits of Optimally Dispatched Plug-In Hybrid Electric Vehicles," Technical Report, NREL/TP-620-40293, July 2006.
3. EPRI, "Environmental Assessment of Plug-In Hybrid Electric Vehicles," Technical Report 1015325, July 2007.
4. C. F. Kutscher, Tackling Climate Change in the U.S." American Solar Energy Society, January, 2007.
5. A. Frank, "Public Utility Commission Policies Decisions for Plug In Vehicles PEV's," July 2009 (<http://www.cpuc.ca.gov/NR/rdonlyres/51327B94-EAE6-440C-AAD2-BA0F63CAB66B/0/AndyFrank.pdf>)
6. P. Mohseni and R. Stevie, "Electric Vehicles; Holy Grail or Fool's Gold," PES 2010 General Meeting, July 2010
7. S. Hadley and A. Tsvetkova, "Potential Impacts of Plug-in Hybrid Electric Vehicles on Regional Power Generation," ORNL/TM-2007/150, January 2008.
8. M. Duvall, "Grid Integration of Plug-In Hybrid and Electric Vehicles," PHEV Executive Summit, January 2009.
9. J. Cogen, "Report of the Alternative Fuel Vehicle Infrastructure Working Group," Oregon State Reports, January 2010.
10. C. Gerkensmeyer, M. Kintner-Meyer, and J. DeSteele, "Technical Challenges of Plug-In Hybrid Electric Vehicles and Impacts to the US Power System: Distribution System Analysis," PNNL-19165, January 2010.
11. S. Bai and S. Lukic, "Optimum Design of an EV/PHEV Charging Station with DC Bus and Storage System," IEEE Energy Conversion Congress & Expo, September 2010.
12. S. Hutchinson, M. Baran, and S. Lukic, "Charging System for a Large Parking Deck," Technical Paper, FREEEDM System, 2010.
13. P. Kulshrestha, K. Swaminathan, M. Chow, and S. Lukic, "Controlling the Charging of PHEVs at a Municipal Parking Deck," Technical Paper, FREEEDM System, 2010.
14. Battelle Energy Alliance, "U.S. Department of Energy Vehicle Technologies Program – Advanced Vehicle Testing Activity Plug-in Hybrid Electric Vehicle Charging Infrastructure Review," Final Report, November 2008.
15. M. Cros, et al, "Light-duty Vehicle Electrification in California: Potential Barriers and Opportunities," Staff Paper, California Public Utility Commission, May 2009.
16. S. Shao, M. Pipattanasomporn, and S. Rahman, "Challenges of PHEV Penetration to the Residential Distribution Network," PES General Meeting 2009, July 2009
17. W. Kempton, et al, "A Test of Vehicle-to-Grid (V2G) for Energy Storage and Frequency Regulation in the PJM System," Mendeley, System, Volume: 2008, November 2008
18. A. Putrus, et al, "Impact of Electric Vehicles on Power Distribution Network," IEEE Vehicle Power and Propulsion Conference, September, 2009.
19. C. Farmer, et al, "Modeling the Impact of Increasing PHEV Loads on the Distribution Infrastructure," This paper appears in: System Sciences (HICSS), 2010 43rd Hawaii International Conference, January 2010.
20. J. Orr, et al, "Current Harmonics, Voltage Distortion, and Powers Associated with Electric Vehicle Battery Chargers Distributed on the Residential Power System," IEEE Trans. On Industry Applications, Volume: IA-20, Issue 4, 1984
21. J. Gomez and M. Morcos, "Impact of EV Battery Chargers on the Power Quality of Distribution Systems," IEEE Power Engineering Review, October 2002.
22. http://docs.cpuc.ca.gov/PUBLISHED/FINAL_DECISION/106042-02.htm#P112_22818
23. M. Kintner-Meyer, et al, "Grid Analysis for Transforming the Transportation Sector from Fossil Fuel to Electricity," RDSI Program Review, October 2008.
24. Curtis Aaron Roe, "POWER SYSTEM IMPACTS OF PLUG-IN HYBRID ELECTRIC VEHICLES, Thesis, Georgia Institute of Technology, August 2009.
25. A. Maitra, et al, "Integrating PEV with the Distribution System," C I R E D 20th International Conference on Electricity Distribution, June 2009.

Ryan Liu (Student)—Mr. Liu is a second-year engineering student at the University of California, Berkeley, expecting to get his Bachelor of Science in Mechanical Engineering in 2013. At UC Berkeley, he works under Professor D.K. Lieu in a Less-Lethal Projectile laboratory. His research interests include renewable energy, plug-in electric vehicle technology, and its effects on the electric grid. He is a member of the UC Berkeley chapter of Engineering Without Borders, the Formula SAE Team, and Pi Tau Sigma (the International Mechanical Engineering Honor Society).

Luther Dow (L'10) is the Senior Director of Distribution and West Coast Operations for Quanta Technology, Oakland, CA. He received his BSEE and MBA from California State University, Sacramento. His areas of expertise include distribution planning, reliability and operation. He is a registered Professional Engineer in the State of California.

W-H Edwin Liu (Fellow)—Dr. Liu received his B.S. degree from National Taiwan University and M.S. and Ph.D. degrees from the University of California, Berkeley. He has extensive experience in consulting, research, and development in the area of energy system analytics, focusing on applying state-of-the-art technologies to energy industry. His expertise is on smart grid, information integration, power system optimization, electricity market modeling, automation, and technology innovations. At Quanta Technology, Edwin is responsible for initiatives in the smart grid and energy management areas. Before joining Quanta, he worked for Siemens/Empros, Pacific Gas & Electric Company, Bechtel, and was a member of the start-up management team of Nexant. Dr. Liu is an IEEE Fellow and former Chairman of the IEEE Computing and Analytical Methods Subcommittee.