Evaluation of DER Adoption in the Presence of New Load Growth and Energy Storage Technologies

Jaesung Jung, Haukur Asgeirsson, Thomas Basso, Joshua Hambrick, Murat Dilek, Richard Seguin, and Robert Broadwater

***Abstract*—This study considers potential system effects from the addition of Plug-in Electric Vehicle (PEV) load to individually metered residential customers together with a concurrent market adoption of Distributed Energy Resources (DER) and energy storage technologies to offset the associated load growth. To evaluate various renewable energy source conditions, a prototypical circuit is evaluated in Detroit, Los Angeles, and Orlando locations for both summer and winter loading conditions. Various load adoption scenarios are simulated by randomly assigning specified loading to target customer classes on the circuit.**

***Index Terms*—Distributed Energy Resource (DER), DER Adoption, Plug-in Electric Vehicle (PEV), Solar Generation, Wind Generation, Energy Storage System, Renewable Energy System.**

I. Introduction

Analysis of concurrent growth or adoption of electric vehicles, distributed energy resources (DER), and energy storage technologies is presented in this paper. In particular, Plug-in Electric Vehicles (PEV), customer owned solar generation, customer owned wind generation, and utility owned battery storage are considered. An objective is to evaluate adoption levels of solar and wind generation supplemented with battery storage that will offset the adoption of electric vehicle loads.

Monte Carlo simulation is used to randomly place DER generation units at locations throughout a prototypical circuit. The simulation provides customer arrival home and plug-in time models, including automated charging during early morning hours.

Technology adoption is modeled as a function of customer billing class. The same billing class can be modeled to adopt different types of PEVs and/or DERs at different adoption levels. Adoption of multiple PEVs by a single customer may be modeled, such as for commercial classes that are expected to employ more than one PEV.

Solar data was imported via the internet from the In My Backyard (IMBY) application from the National Renewable Energy Lab (NREL) [1]. For a given solar generation location and size, the NREL interface provides hourly generation data for an entire year, and 8760 hours of generation from year 2004 are used in the analysis hear. For the wind generation, wind speed data is obtained using U.S Local Climatological Data from the National Climatic Data Center (NCDC) [2]. The wind power used in this analysis is calculated by the wind turbine power equation. For each hour of analysis, customer loads are estimated from averaged hourly SCADA measurements, hourly customer kWHr load data, and monthly kWHr load data processed by load research statistics to create hourly loading estimates for each customer [3, 4].

A distribution circuit with 1404 residential, 30 commercial and small industrial class customers are used in the analysis. The circuit is used to analyze both summer and winter conditions for three selected cities, Detroit, Michigan, Los Angeles, California, and Orlando, Florida. Of particular interest is what levels of DER adoption and battery storage would be needed to offset the adoption of the PEV loads.

A base case where just PEV adoption is considered is used to establish feeder load characteristics due to the new PEV loads along with primary overloads that are caused by the new PEV loads. The study then proceeds to evaluate how DER adoption levels and battery storage strategies could compensate for the PEV loads to help manage feeder overloads. The results of summer and winter analysis are presented for Detroit, Los Angeles, and Orlando locations with various adoption scenarios. Analysis results are then considered followed by a comparison between the results obtained from Detroit, Los Angeles, and Orlando. Findings of the study are summarized.

II. Simulation Assumptions and Profile

A. Native Load Profile

The sample system used for this study has a substation serving 1404 individually metered residential customers. From an available set of residential load measurements, two groups of January and July load profiles are selected to evaluate the seasonal effects for summer and winter months. Figure 1

J. Jung is a graduate student in the Dept. of ECE at Virginia Polytechnic Institute and State University, Blacksburg, VA 24060 USA (e-mail: jjaesung@vt.edu).

H. Asgeirsson is the manager of Power System Technology Dept., DTE Energy, Detroit, MI 48226 USA (e-mail: asgeirssonh@dteenergy.com).

T. Basso is with the National Renewable Energy Laboratory, Golden, CO 80401 USA (e-mail: Thomas.Basso@nrel.gov).

J. Hambrick is with the National Renewable Energy Laboratory, Golden, CO 80401 USA (e-mail: Josh.Hambrick@nrel.gov)

M. Dilek is with Electrical Distribution Design, Inc., Blacksburg VA 20460 USA (e-mail: murat-dilek@edd-us.com).

R. Seguin is with the Department of Distributed Resource Planning, DTE Energy, Detroit, MI 48226 USA (e-mail: seguinr@dteenergy.com)

R. P. Broadwater is with the Dept. of ECE at Virginia Polytechnic Institute and State University, Blacksburg, VA 24060 USA (e-mail: dew@vt.edu).

presents a percent loading profile during winter and summer, respectively. These load profiles shows a baseline condition before DER adoption with near-peak conditions occurring from the hours of 4 PM through 11 PM and no overloaded distribution transformers.

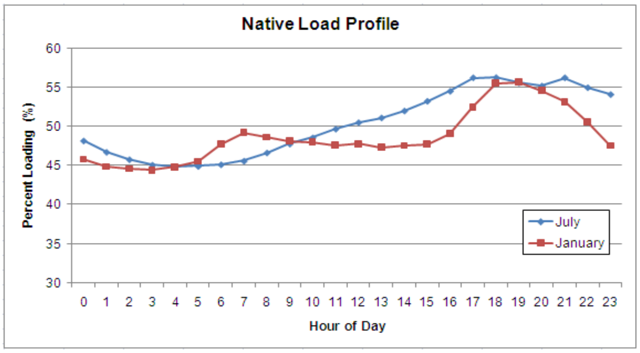


Fig. 1. Native Percent Loading during Summer and Winter

B. PEV Load Profile

Since PEV automobile technology is new to the mass market, information on how consumers will utilize this new technology is not available.

In this study the batteries of the PEV are assumed to be charged only at residential homes. It is also assumed that the battery is fully discharged when PEV charging of 8kWh occurs once a day. This assumption provides the worse case scenario. There are two likely voltages at residential locations, 120V and 240V [5]. This study uses a 120V charging scenario as illustrated in Figure 2, supplied by a 120V/15A circuit charging at an essentially constant demand of around 2kW for five hours. Choosing 120V instead of 240V charging results in overloads occurring earlier and provides the worse case scenario. In the simulation for a given consumer the charging is a function of arrival time as discussed below.

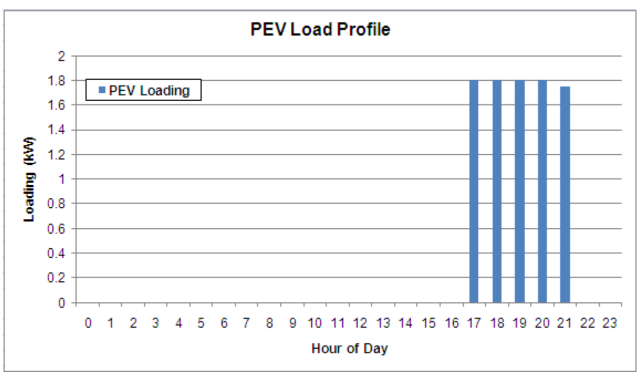


Fig. 2. Typical 120V/15A Charging Profile for PEV

C. Solar Generation Profile

To analyze potential solar benefits of customer owned solar generation, a 2kW solar photovoltaic (PV) array for distributed generation is assumed. The study considers the solar incidence for the defined geographical locations in July and January. The solar generation back to the grid is based on data from the In My Backyard (IMBY) tool from NREL for the average solar incidence for two 1kW panels per installation.

D. Wind Generation Profile

For the assessment of wind energy potential, a 2kW wind turbine for distributed generation is assumed. The hourly mean wind speed is obtained from the NCDC for the defined geographical locations in July and January 2010 [2]. Then, the wind power produced is calculated by using wind speed:

$$P_{wind} = \frac{1}{2} \cdot \rho \cdot A \cdot v^3 \cdot c_p$$

where ρ is the air density, A is the area cleared by the rotor, v is the wind speed, and c_p is the efficiency of the turbine. In this study, the wind power is calculated at 15°C and 1 atm pressure which is 1.225 kg/m^3 air density contained in 3.5 m rotor with 45% efficiency.

E. Storage Profile

The study also considers battery storage in combination with renewable energy, which stores the renewable energy production for later retrieval with 80% efficiency. While the real-time renewable energy configuration produces more total energy, it has effectively no impact on the peak residential demands without control. However, when coupled with a storage system, the renewable energy generation is able to significantly influence peak characteristics, especially during the peak growth scenario driven by an emerging PEV market. In this study it is assumed that the storage system stores renewable energy production and returns to the system during the 7 hour near-peak duration from 5 PM to 12 PM.

III. Case Studies

A. Simulation Methodology

The distribution circuit to be analyzed is shown in Figure 3. This circuit has 1404 residential, 30 commercial, and small industrial customers with 90%, 9% and 1% of the total load, respectively.

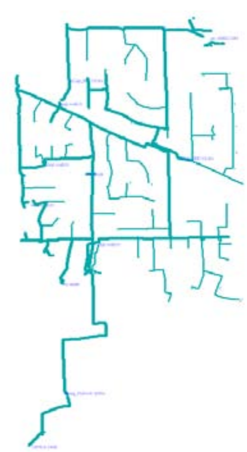


Fig. 3. Distribution Circuit to be Analyzed

This study utilizes a relatively conservative PEV adoption rate of one percent per year for residential customers over the next ten year period. It assumes the typical PEV owner would tend to initiate recharging upon returning home from the work. Thus, knowing the pattern of people arriving home from work will provide a probability distribution of when PEV charging will begin. By applying a Monte Carlo simulation to the census data and relating travel time to miles traveled [6], a profile of people arriving home from work and the average number of miles people travel to and from work was obtained. The profile developed is in Figure 4 and shows the distribution of arrival times at home. This also assumed to represent the distribution of when PEVs will begin charging.

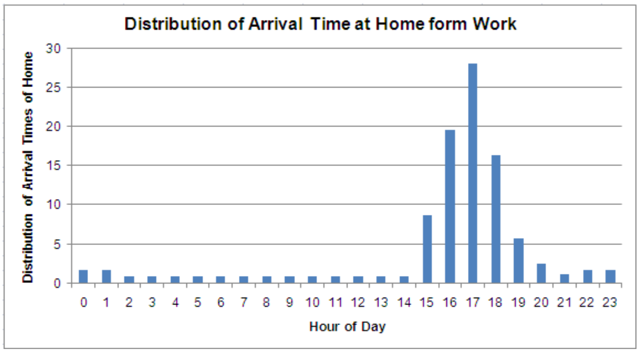


Fig. 4. Distribution of Arrival Times at Home from Work

The study considers an aggressive ten year renewable energy (solar, wind) adoption rate of 3% per year, to analyze potential renewable energy source benefits with 30% of the residential customers having a 2kW renewable energy system for distributed generation. The generation impacts are also analyzed with storage system adoption rates of 3% per year over the same period. The storage systems could be provided by and controlled by the utility

Figure 5 presents the outline of the DER adoption algorithm. After the selection of a seasonal load profile and adoption levels of the customer class, the DER adoptions are randomly placed. This process is repeated until the selected adoption levels have been reached. System impacts are then analyzed in terms of induced component overloads and low-voltage conditions.

The investigation analyzes the inherent variation in the performance of renewable energy resources by evaluating the same prototypical circuit during winter and summer loading conditions at three distinct geographic locations: northern (Detroit), middle (Los Angeles), and southern (Orlando), with the scenarios shown in Table 1.

TABLE I
SCENARIOS OF DER ADOPTION ANALYSIS

	PEV	Solar Gen.	Storage (Solar)	Wind Gen.	Storage (Wind)
Base	×	×	×	×	×
Case 1	10 %	×	×	×	×
Case 2	10 %	30 %	×	×	×
Case 3	10 %	×	30 %	×	×
Case 4	10 %	×	×	30 %	×
Case 5	10 %	×	×	×	30 %
Case 6	10 %	10 %	×	10 %	×

B. Solar Generation

The resulting solar generation profile is shown in Figure 6 for each location in January and July. In this figure solar production is represented as negative load. This component data is then used to define the solar and storage components modeled per installation for the DER adoption analysis.

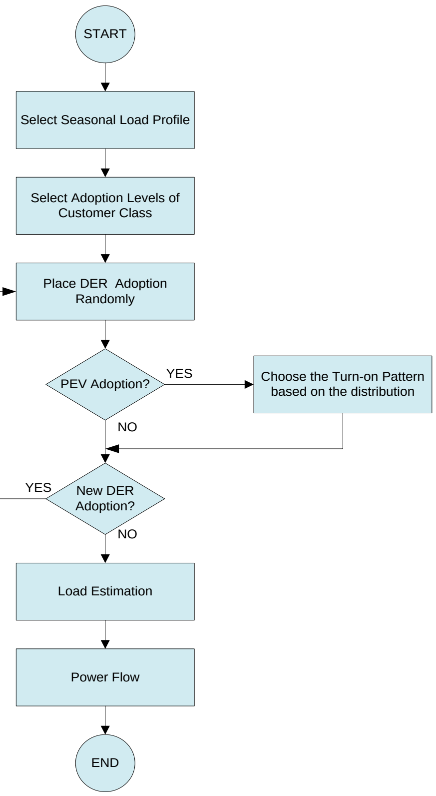
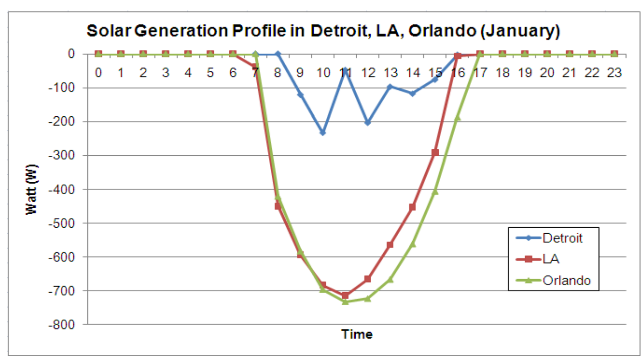
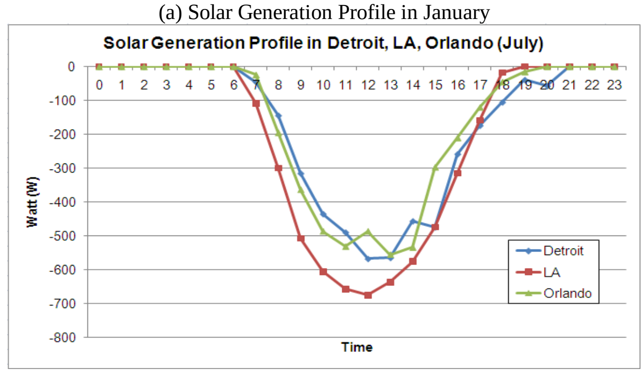


Fig. 5. Flowchart of DER Adoption Analysis



(a) Solar Generation Profile in January



(a) Solar Generation Profile in July

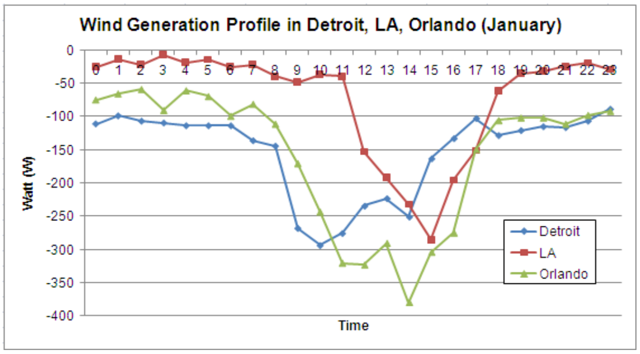
Fig. 6 Solar Generation Comparison by Location (2kW PV Array)

It was found that similar solar generation is produced during the summer in LA (5.0kWh), Detroit (4.1kWh), and

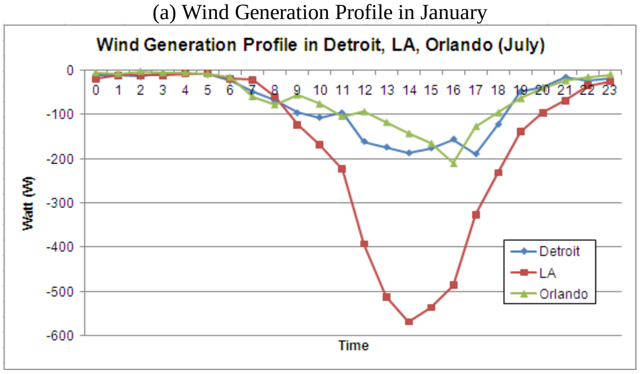
Orlando (3.9kWh). In winter, comparable results are obtained between LA (4.5kWh) and Orlando (5.0kWh), while in Detroit (0.8kWh) there is noticeably less generation over the same period [7]. Furthermore, Orlando produces slightly more solar energy during winter than summer which provides a different pattern from the other two cities.

C. Wind Generation

Figure 7 compares the wind generation profile for each location in January and July. The figure shows the estimated negative load produced by wind generation. These results indicate that wind generation fluctuates more than solar generation but can produce energy during both day and night.



(a) Wind Generation Profile in January



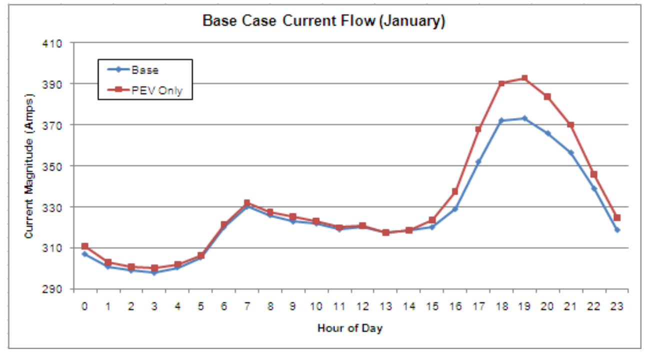
(b) Wind Generation Profile in July

Fig. 7 Wind Generation Comparison by Location (2kW Wind Turbine)

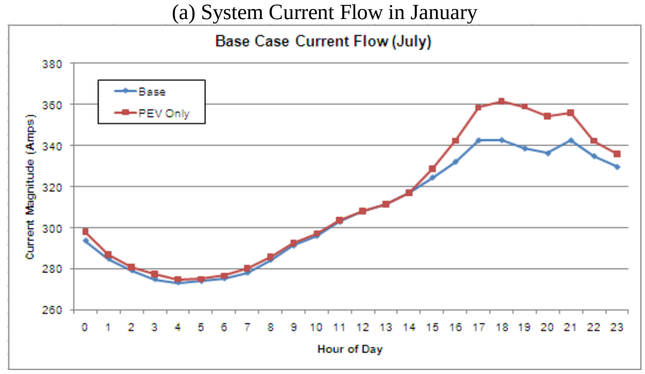
It was found that Detroit (3.7kWh) and Orlando (3.8kWh) produce more wind generation than LA (1.7kWh) for the winter period. However, LA (4.1kWh) has more wind generation during summer than Detroit (1.8kWh) and Orlando (1.6kWh). A similar pattern is observed between Detroit and Orlando for wind generation. Note that smaller amounts of wind generation are observed in the three selected cities because of the lack of wind resources in large cities.

D. Reference Case

To understand the capability of DER generation and storage technology in offsetting a growing PEV market demand and induced overload conditions, a reference case is considered. Figure 8 shows the current flow for the prototypical circuit, measured at the substation, with 10% residential PEV adoption in January and July as a reference case. As expected, the majority of additional PEV loading is delivered in the near-peak period, and thus the peak current magnitude increases, resulting in system overloading conditions.



(a) System Current Flow in January



(a) System Current Flow in July

Fig. 8 System Current Flow for Base Case by DER Adoption

Figure 9 shows that the charging scheme has a substantial influence on the number of overloaded components resulting from the PEV introduction. From 2 to 10 percent PEV adoption rates, the number of induced component overloads is seen to vary from around 1 to 2 for January, while ranging from around 1 to 6 for July.

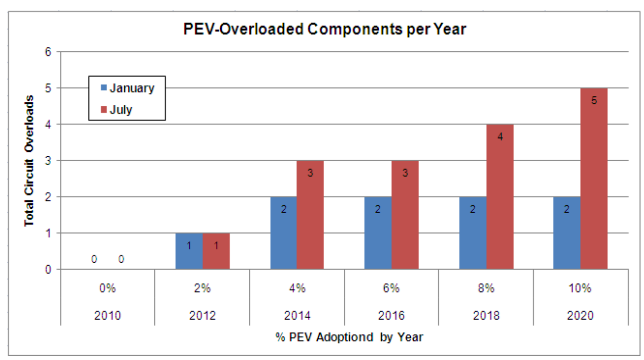


Fig. 9 Number of PEV-Induced Overloaded Components

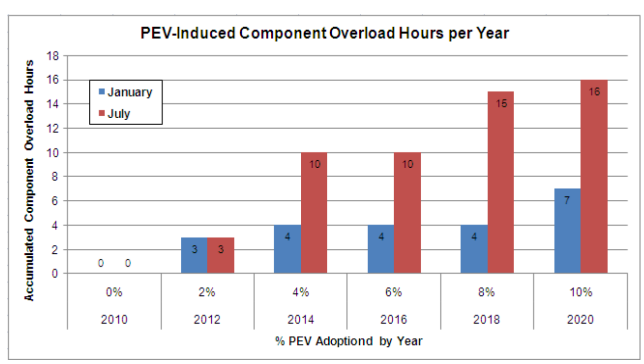
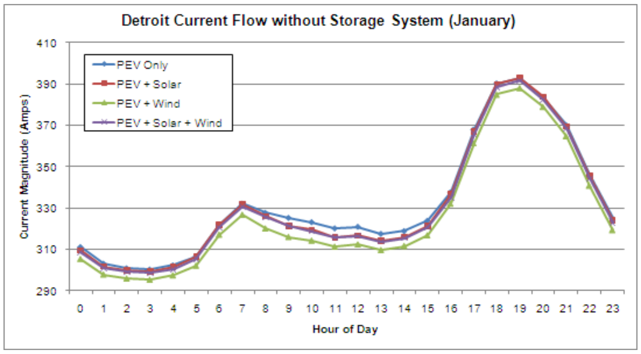


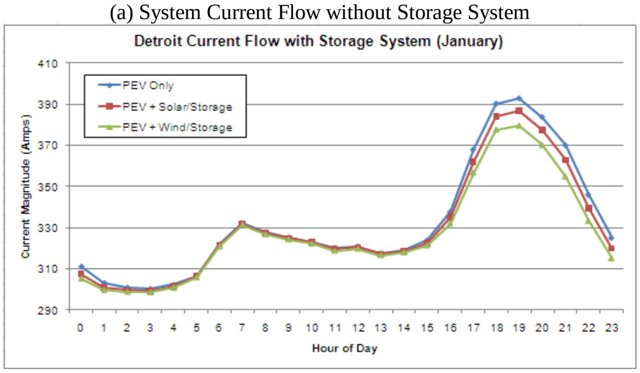
Fig. 10 Accumulated Component Overload Hours

However, the range in the cumulative overloaded component hours for the same PEV adoptions varies from 3 to 7 hours for January and from 3 to 16 hours for July as indicated in Figure 10. Thus, more components are overloaded and remain in the overloaded state for a longer time period during summer.

IV. Test Results

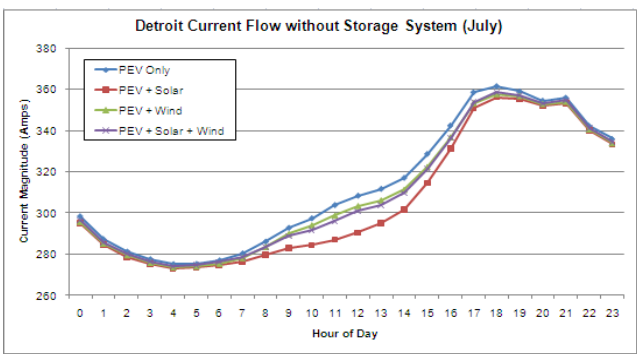


(a) System Current Flow without Storage System

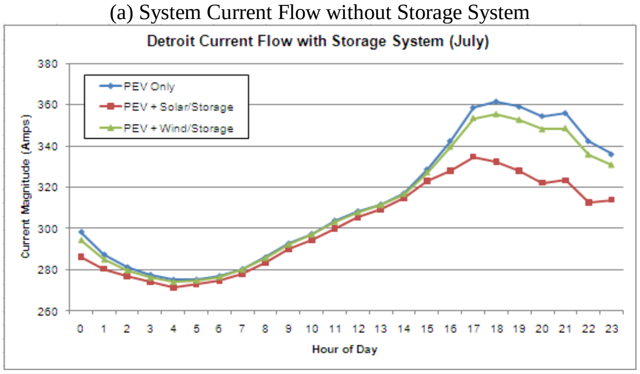


(b) System Current Flow with Storage System

Fig. 11 System Current Flow for Detroit by DER Adoption in January



(a) System Current Flow without Storage System



(b) System Current Flow with Storage System

Fig. 12 System Current Flow for Detroit by DER Adoption in July

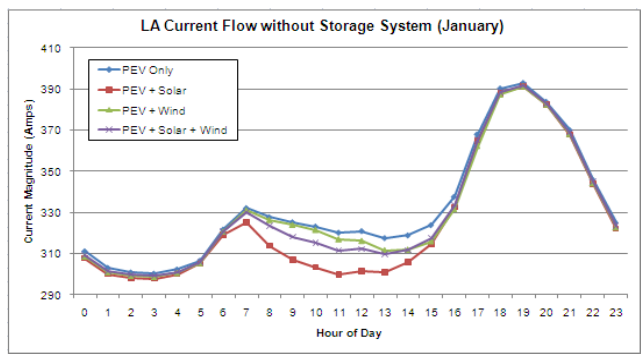
A. Detroit Case

Figures 11 and 12 show results of the start-of-circuit current flow comparisons among the various scenarios of Table 1 considered in January and July in Detroit. As illustrated in Figure 11, during winter, none of the DER generation scenarios coupled with PEV growth causes the current level to fall below the base system peak demand. The impact from solar generation is notably less during the winter but the wind generation helps offset the new PEV loads.

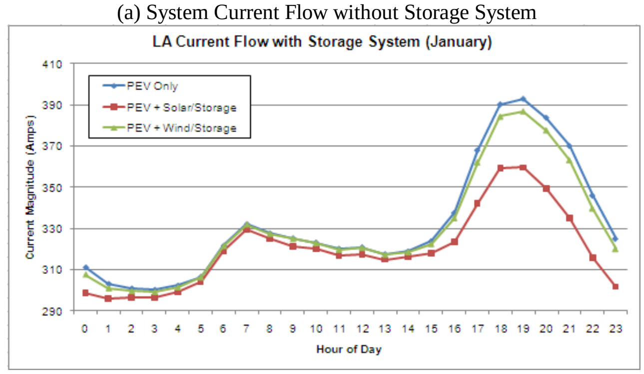
Figure 12 shows that for case 2, solar generation during summer, results in midday demand dips but has little impact on peak demands. With the projected PEV recharging occurring during the existing peak, the solar-storage combination is able to clip the increased peak demand to a level below that of the base system. However, for case 4, wind generation, only shows marginal improvements.

B. Los Angeles Case

Figures 13 and 14 show the current flow for Los Angeles, measured at the substation, with the various scenarios considered in January and July. For cases 2 and 4 during the winter period, shown in Figure 13, standalone solar and wind generation level out the midday demand but have little impact on peak demand. With the combination of wind and solar generation for case 6, similar results are obtained. However, when coupled with the storage system, the solar generation reduced peak current flow in the system by approximately 7%. However, wind generation had little effect on peak demand.



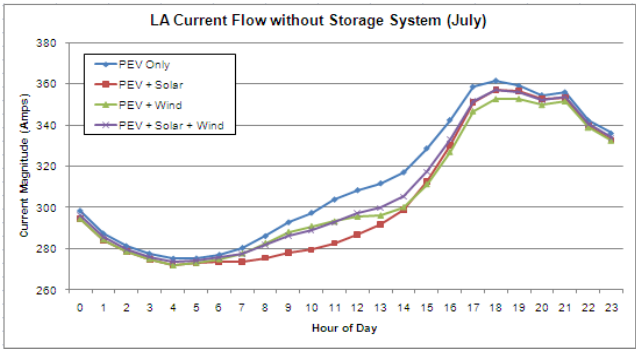
(a) System Current Flow without Storage System



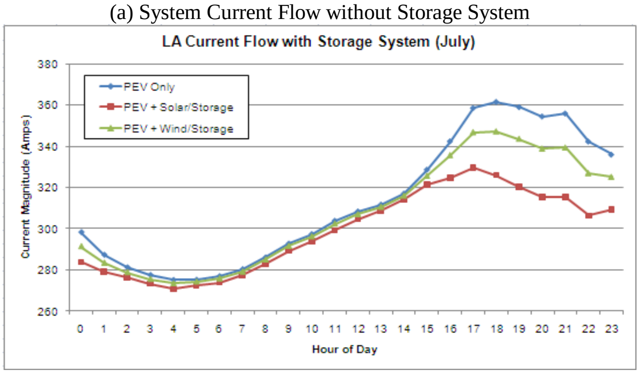
(b) System Current Flow with Storage System

Fig. 13 System Current Flow for Los Angeles by DER Adoption in January

For the summer period shown in Figure 14, standalone solar and wind generation again have a negligible impact on the peak demand period, but essentially flattened the current flow when coupled with the storage system. In summer, both wind and solar generation are capable of reducing the peak demands induced by PEV charging.



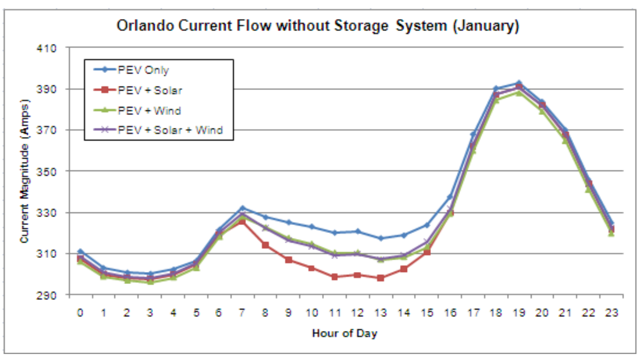
(a) System Current Flow without Storage System



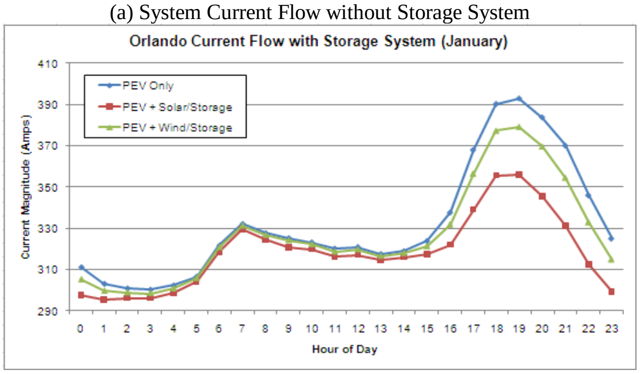
(b) System Current Flow with Storage System

Fig. 14 System Current Flow for Los Angeles by DER Adoption in July

C. Orlando Case



(a) System Current Flow without Storage System

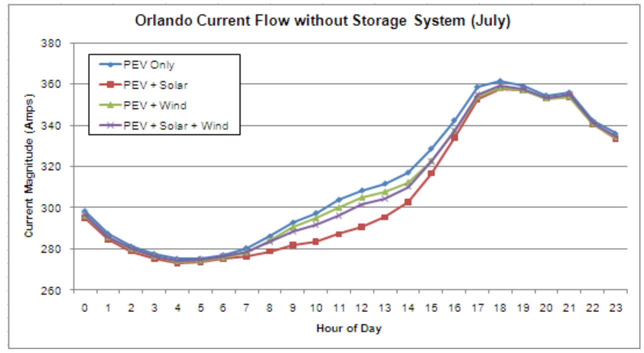


(b) System Current Flow with Storage System

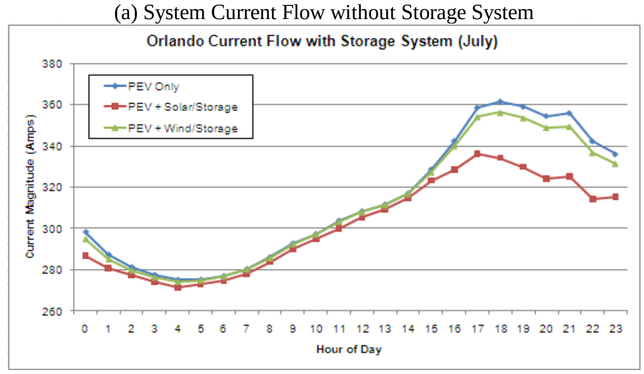
Fig. 15 System Current Flow for Orlando by DER Adoption in January

Figures 15 and 16 show current flow variations by system configuration in January and July in Orlando. Although standalone solar and wind generation are not available during the projected residential PEV market recharging period, in combination with the storage system can offset a growing PEV market demand for the winter period shown in Figure 15.

Figure 16 shows solar-storage impacts on the induced PEV demands during the summer period, when stored solar energy is recovered during the peak period. It also shows the diminished benefits of wind generation.

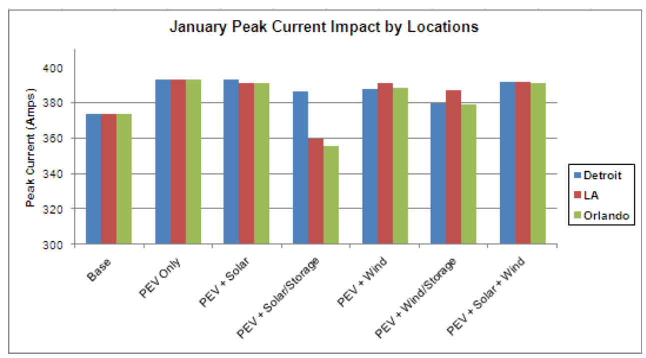


(a) System Current Flow without Storage System

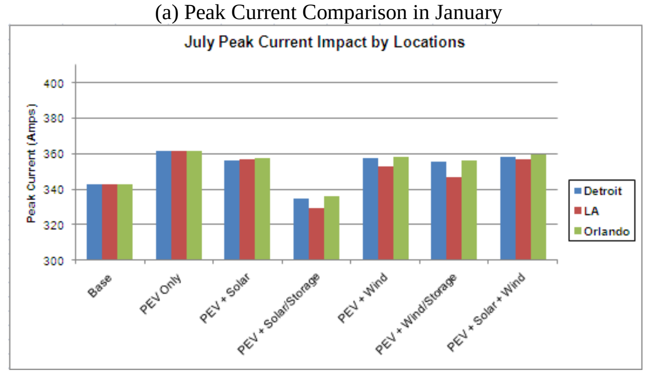


(b) System Current Flow with Storage System

Fig. 16 System Current Flow for Orlando by DER Adoption in July



(a) Peak Current Comparison in January



(b) Peak Current Comparison in July

Fig. 17 Peak Current Comparison by Location

D. Case Study Comparison

Figure 17 summarizes peak current flow comparisons by location for the various scenarios. The results illustrate that a customer owned solar market could produce some significant impacts on current energy consumption profiles, primarily of benefit to utilities when coupled with an efficient battery storage device, which is needed to affect peak demands. The benefit of customer owned solar generation with battery storage is consistent for all locations during the summer analysis, where the applied solar generation is able to completely offset the added PEV loading. For the winter period, LA and Orlando are comparable in reducing the PEV-induced demand, while the Detroit location shows significantly less benefit.

However, a customer owned wind market shows less benefit, even in combination with battery storage because there is less wind resource in the large, developed cities. Furthermore, standalone solar and wind generation have negligible impact on the peak demand period, as most of the generation occurs during the off-peak period for the predominantly residential feeder considered.

V. Conclusion

The results demonstrated that a maturing PEV market could produce significant impacts on peak demand, resulting in additional system overloading conditions. Thus, the study considers solar and wind generation, as well as in combination with battery storage system to control the associated peak demand growth driven by an emerging PEV market.

While the solar configuration produces more total energy, it has effectively no impact on the peak residential demands, which typically occur during times when solar generation is unavailable. However, when coupled with a battery storage system, the solar generation is able to significantly influence peak characteristics, especially during the peak growth scenario driven by an emerging PEV market. The study shows that in LA and Orlando, 30% adoption of solar generation could offset a 10% PEV adoption. This is also true in Detroit in the summer, but not the winter.

The "available at night" wind configuration shows less benefit, even in combination with battery storage system because of the lower total energy from the wind resource. The study shows that in the three selected cities, 30% adoption of wind generation could help to reduce the peak demands induced by 10% PEV adoption, but not offset the PEV loading.

VI. References

[1] NREL: In My Backyard (IMBY) Home Page [Online]. Available: http://www.nrel.gov/eis/imby/

[2] National Climatic Data Center (NCDC) Home Page [Online]. Available: http://www.ncdc.noaa.gov/oa/climate/climatedata.html

[3] R. P. Broadwater, A. Sargent, A. Yarali, H. E. Shaalan, and J. Nazarko, "Estimating Substation Peaks from Load Research Data," *IEEE Trans. Power Delivery*, vol. 12, pp. 451-456, Jan. 1997.

[4] A. Sargent, R. P. Broadwater, J. C. Thompson, and J. Nazarko, "Estimation of Diversity and KWHR-to-Peak-KW Factors from Load Research Data," IEEE Trans. Power Systems, vol. 9, pp. 1450-1456, Aug. 1994.

[5] J. Taylor, A. Maitra, M. Alexander, D. Brooks, and M. Duvall, "Evaluation of the Impact of Plug-in Electric Vehicle Loading on Distribution System Operations," in *Proc. 2009 IEEE PES General Meeting*, pp. 1-6.

[6] U.S. Census Bureau 2000 Data [Online]. Available: http://www.census.gov/

[7] NREL: Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors [Online]. Available: http://rredc.nrel.gov/solar/pubs/redbook/

[8] K. Schneider, C. Gerkensmeyer, M. Kintner-Meyer, and R. Fletcher, "Impact assessment of plug-in hybrid vehicles on pacific northwest distribution systems," in *Proc. 2008 IEEE PES General Meeting*, pp. 1-6.

[9] K. Clement, E. Haesen, and J. Driesen, "Coordinated Charging of Multiple Plug-In Hybrid Electric Vehicles in Residential Distribution Grids," in *Proc. 2009 IEEE PES Power Systems Conference and Expositions*, pp. 1-7.

[10] C. Roe, A. P. Meliopoulos, J. Meisel, and T. Overbye, "Power System Level Impacts of Plug-In Hybrid Electric Vehicles Using Simulation Data," in *Proc. 2008 IEEE Energy 2030 Conference*, pp. 1-6.

[11] S. W. Hadley and A. Tsvetkova. 2008. Potential Impacts of Plug-in Hybrid Electric Vehicles on Regional Power Generation. ORNL/TM-2007/150. Oak Ridge National Laboratory, Oak Ridge, TN.

VII. Biographies

Jaesung Jung (SM'08) is currently working towards his Ph. D's in Electrical Engineering at Virginia Polytechnic Institute and State University, Blacksburg. He received the M.S. degree form the Department of Electrical and Computer Engineering at North Carolina State University, Raleigh in 2009. His research interests include the development and deployment of renewable and sustainable energy technologies.

Haukur Asgeirsson (M'78) is the manager of Power System Technologies at DTE Energy, responsible for employing distributed resources into the distribution planning and operating process. Since 2002, he has installed 20 projects to support the distribution system totaling nearly 20 MW. His group also manages interconnections and is a champion of Smart Grid technology solutions. Haukur received his BSEE and MSEE degrees from the University of Michigan. He is a member of the IEEE PES and a licensed professional engineer in the State of Michigan.

Thomas Basso (M'81) received his BE and MS in Engineering Science from State University of New York at Stony Brook. Basso is a senior engineer at NREL and Interconnection Engineering and Standards technical lead under the NREL Distributed Energy and Electricity Reliability Program. He is secretariat for IEEE Standards Coordinating Committee 21 on Fuel Cells, Photovoltaics, Dispersed Generation, and Energy Storage and is the USA co-technical advisor and administrator for the USA Technical Advisory Group International Electrotechnical Commission Technical Committee 8 System Aspects of Electrical Energy Supply.

Joshua Hambrick (M'05) received the B.S. and M.S. degrees from Virginia Polytechnic Institute and State University (Virginia Tech), Blacksburg, VA, in 2000 and 2006, respectively. He is currently pursuing the Ph.D. degree at Virginia Tech.

He is currently a Senior Engineer at the National Renewable Energy Laboratory in Golden, CO. His research interests include modeling and simulation of distributed generation and impact analysis of high penetration of renewable resources on distribution systems.

Murat Dilek received the M.S. and Ph.D. degrees in electrical engineering from Virginia Tech, Blacksburg, in 1996 and 2001, respectively.

He is a Senior Development Engineer at Electrical Distribution Design, Inc. His work involves computer-aided design and analysis of electrical power systems.

Richard Seguin (M'71) received the B.S. degree in electrical engineering in 1971 from Clarkson University, Potsdam, NY, and completed graduate courses in electrical engineering and environmental and hazardous waste management at Wayne State University, Detroit, MI.

He is a Principal Engineer of Distributed Resources at Detroit Edison. He has championed several applications for the electrical system planning and operations areas, with a focus on customer power quality and capital utilization.

Robert P. Broadwater (S'68–M'71) is a Professor in power systems and software engineering at Virginia Tech, Blacksburg. He works in the area of computer-aided engineering and generic analysis.