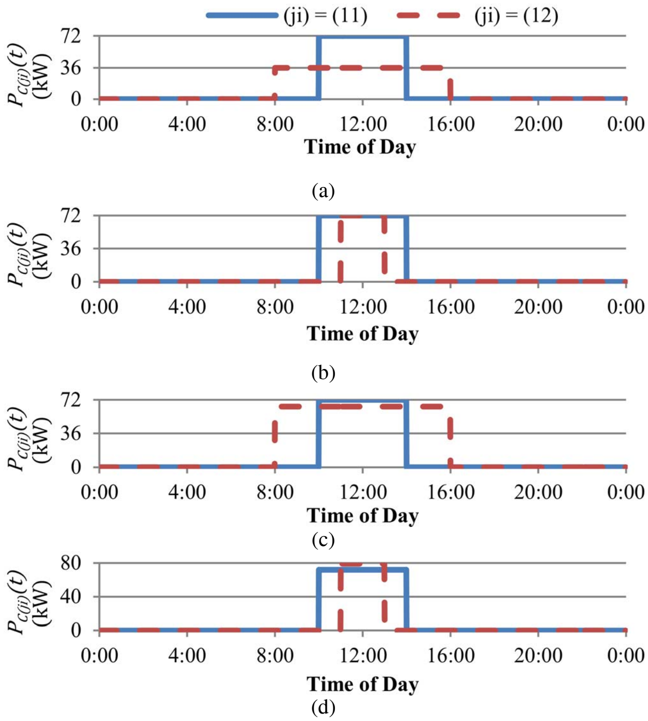

Fig. 6. The four PEV charging profiles analyzed in the university campus case study. The two profiles indicate the aggregate power drawn by the ten chargers installed in each of the two parking garages. In each scenario, one garage draws 72 kW for 4 hours. The other garage draws as follows: (a) the same amount of energy but at half the power, (b) the same amount of power but only half the energy, (c) 10% less power but more energy, and (d) 10% more power but less energy when compared to the first garage.

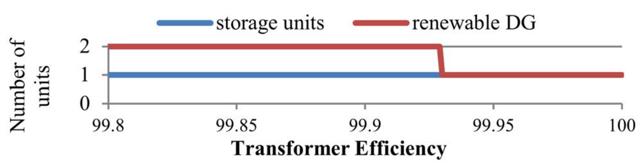

Fig. 7. Optimal number of DG and storage units in the optimal design as a function of transformer efficiency, assuming charging profiles of Fig. 6(a).

To demonstrate its usefulness, this methodology is used to study optimal system designs for two public charging case studies.

In the case of a retail business looking to deploy two PEV chargers and investigating whether or not to also deploy renewable DG and storage to avoid a demand charge, it is shown that if charging is coincident in time with DG power production, the optimal design is one that uses solar DG and the minimum amount of lead-acid storage needed to limit the amount of power drawn from the grid to below the level that triggers a demand charge. However, if charging is not completely coincident with DG power production, the optimal design decision depends on the level of existing load. When net metering is allowed, the general design decisions do not change; however the level of existing load at which the breakeven between a system with and without renewable DG and storage is achieved changes.

In the case of a university campus looking to deploy multiple chargers in two parking garages located far enough apart that that distribution system losses between charger locations cannot be ignored, it is shown that the number, size and location of the renewable DG and storage unit depends on, among other things, the level of coincidence between PEV charging and renewable DG power production and the amount of distribution system losses. In all the cases analyzed, one storage unit is optimal and it is located close to the PEV chargers that draw the most energy

ACKNOWLEDGMENT

The authors wish to acknowledge the guidance and support of Yaosuo Xue, Dr. Gerd Griepentrog and John Hurley of Siemens Corporate Technology. We also wish to thank Ali Afridi of Lexington High School for help with processing the solar irradiation data.

REFERENCES

[1] Hybridcars.com, *Hybrid Market Dashboard* [Online]. Available at: http://www.hybridcars.com/market-dashboard.html , Sep. 13, 2012

[2] Supplemental Tables to the Annual Energy Outlook 2012, US Energy Information Administration (EIA), Department of Energy, Washington, DC, June, 2012.

[3] D. Mead, "Top Five Electric Vehicle Initiatives of the Year," *Greentech Media*, Dec. 8, 2011.

[4] D. Karner,. *Clean Cities Webinar* [Online]. Available at: http://www.theevproject.com/cms-assets/documents/70198-833686.clean-cities-webinar.pdf, June 25, 2012

[5] J. G. Kassakian, R. Schmalensee, T. D. Heidel, K. K. Afridi, D. J. Perreault, S. J. Gunter, et al., *The Future of the Electric Grid*, Massachusetts Institute of Technology, 2011.

[6] E. Wesoff, "Envision's Solar PV Building in a Box," Greentech Media, Oct. 1, 2010.

[7] A. Smith and G. Gill, *Toward Zero Carbon: The Chicago Central Area DeCarbonization Plan*, Mulgrave, Victoria, Australia: The Images Publishing Group Pty Ltd, 2011, ch. 3, sec. 8, pp. 218-219.

[8] E. Wesoff, "Solar Frontier CIS PV Panels Charging the Nissan Leaf," *Greentech Media*, July 11, 2011.

[9] N. Halverson, "Electric Vehicle Charger Powered by Wind and Solar," *Discovery News*, July 28, 2011.

[10] D. Xu, L. Kang, L. Chang, and B. Cao, "Optimal sizing of standalone hybrid wind/PV power systems using genetic algorithms," in Proceedings of the Canadian Conference on Electrical and Computer Engineering, Saskatoon, SK, Canada, May 2005, pp. 1722-1725.

[11] B. S. Borowy and Z. M. Salameh, "Methodology for Optimally Sizing the Combination of a Battery Bank and PV Array in a Wind/PV Hybrid System," *IEEE Transactions on Energy Conversion*., vol. 11, no. 2, pp. 367-375, June 1996.

[12] A. Gupta, R. P. Saini, and M. P. Sharma, "Hybrid Energy System Sizing Incorporating Battery Storage: An Analysis via Simulation Calculation," in Proceedings of the 2009 3rd International Conference on Power Systems, Kharagpur, India, Dec. 2009.

[13] *IEEE Recommended Practice for Sizing Lead-Acid Batteries for Stand-Alone Photovoltaic (PV) Systems*, IEEE Std. 1013-2007, 2007.

[14] S. J. Gunter, K. K. Afridi, and D. J. Perreault, "Optimal Design of Grid-Interfaced EV Chargers with Integrated Generation," in Proceedings of the IEEE PES Innovative Smart Grid Technologies (ISGT) Conference, Washington, D.C. Jan. 16-20, 2012.

[15] S. J. Gunter, "Methodology for Combined Integration of Electric Vehicles and Distributed Resources into the Electric Grid," M.S. Thesis, Department of Electrical Engineering and Computer Science, Massachusetts Institute of Technology, Cambridge, MA, 2011.

[16] National Renewable Energy Laboratory, *Solar Resource & Meteorological Assessment Project (SOLRMAP): Loyola Marymount University* [Online]. Available at: http://www.nrel.gov/midc/lmu/ , July 11, 2011