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SOLAR PARKING STRUCTURE FOR PLUG-IN ELECTRIC VEHICLES

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Abstract Plug-in electric vehicles are rapidly becoming viable options for consumer use as regular transportation. Charging solutions that are both intelligent and renewable are therefore needed to meet the challenges of integrating these into the existing power grid and future smart grid. A solar photovoltaic parking structure for charging these vehicles is proposed and modeled that includes on-site power storage, a grid connection to a nearby building, and coordination with the local utility through demand response. Computer-based intelligent power management is realized by expert control of the sources, loads, and storage components. This parking structure is also designed to facilitate research and serve as an educational opportunity for university students.

1. INTRODUCTION

As consumers increase their adoption of plug-in electric vehicles (PEVs), which includes plug-in hybrid electric vehicles (PHEVs), more charging options and locations will become necessary. In section 1.1, we will see that this becomes significant in the near future. Having an infrastructure that facilitates this will require novel ideas, such as: strategic incorporation of charging stations with the power grid, e.g. smart grid; renewable power options at charging stations; research opportunities for testing new devices; and educational opportunities for students who would develop these new charging station installations.

Proposed is a solar photovoltaic (PV) parking structure (SPS) that serves as a charging station for PEVs. This structure is unique as it includes computer-based intelligent power management for strategic cooperation with demand response (DR) levels as well as local power storage to enhance management of the power resource. Strategies are accommodated for both managing power on the load side, i.e. the vehicles, as well as supply side, i.e. power grid utilization. Finally, the SPS will be constructed at a university location and designed to afford students the ability to: understand power generation and utilization; develop intelligent power management algorithms; and test new hardware, e.g. novel solar panels and batteries.

PEVs coming onto the market

U.S. consumers purchase millions of vehicles each year. With the price of gasoline elevated for the past few years, PHEVs and PEVs are rapidly growing in acceptance. As millions of these vehicles come onto the roads, and subsequently plug into the power grid, the power grid will become stressed in new ways. A number of studies have been done to gauge the effect of PEVs on the power grid and intelligent management of these vehicles will become necessary to continue stable operation of the grid. One major concern is the increased long-term load put onto the grid by PEVs. This increased load may cause some lines or substations to become overloaded sooner rather than later, which in turn would reduce the life of the electrical equipment. [1] However, PEVs' batteries could become an important resource for storing energy such as that produced from renewable sources. [2]

Fig. 1 illustrates the U.S. consumer interest for PEVs with a 40-mile range or greater with 48% either very to extremely interested in their next vehicle purchase being a PEV. [3]

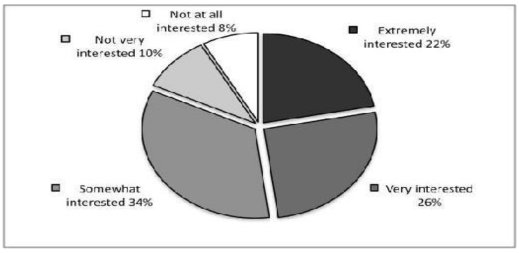

Fig. 1 – Consumer interest for plug-in vehicles, adapted from [3].

It is especially interesting to note with respect to Fig.1 that most consumers replace their vehicle every 3-5yrs. Therefore, this will become a significant issue in the very near future.

Solar PV parking structures at other locations

In January 2010, the University of Central Florida opened a solar charging station for electric vehicles and in February it began feeding back power to the main power grid of the campus. The charging station provides a parking spot as well as charging outlets for four vehicles. Construction of the project began in November 2009, with the total cost of the project being $380,000, all of which was funded by a research grant from the Florida Energy Systems Consortium.

Because of the abundant sunlight, there is no charge for the electricity consumed unless a vehicle consumes more than 10kWh of energy. [4]

In August 2010, a solar parking structure with charging outlets was opened in Pulaski, TN. The 20kW solar array parking structure cost $180,000, most of which were paid for by federal and state funds. With the release of the Nissan Leaf [7] and Chevrolet Volt [8] in late 2010, similar charging stations are set to open in Nashville and Chattanooga, while fourteen more are scheduled to open in Tennessee in the next three years. [5]

In September 2010, Lane Community College in Eugene, OR opened a solar charging station for electric vehicles on the west side of campus. The charging station provides eighteen covered charging stations. Construction began in June 2010 and cost $800,000, most of which was funded by the community college through bond funds. The parking structure will also be used as a learning lab for students. [6]

In these projects, solar photovoltaic power is used to supply or at least offset the power grid supply for PEV charging. Intelligent power management, such as vehicle prioritization and handling demand response, does not currently seem to be a theme in these cases. Also, on-site power storage for more advanced capabilities is not included or investigated. While Lane Community College specifically states that its SPS will also be utilized for educational purposes, it is likely that students at the University of Central Florida and following educational institutions will have such opportunities.

2. PROJECT DESCRIPTION

The proposed SPS will consist of five parking spaces, each space covered with 2kW DC of solar panels, for a system total of 10kW DC. The choice of five spaces allows a cost efficient structure to be built for evaluation as a pilot project. Expansion to larger/multiple structures then follows as a scale of this structure.

A single computer workstation will provide a user interface for monitoring the SPS and implementing the intelligent power management. Each space will have a 120V AC charging station to both provide and meter the energy to the respective PEV. The Nissan Leaf is chosen to be a typical all-electric PEV with 24kWh of on-board energy storage and a ~2kW 120V charge rate. [7] Other vehicles are considered similar.

A 24kWh battery is also included to facilitate power management strategies discussed in section 3.2. This size is chosen to be roughly equivalent to the size of a single PEV battery for both economic and physical space considerations. Larger battery sizes would allow greater flexibility in power management but at greater cost. This sizing also allows prototype PEV batteries to be easily evaluated in the system if desired.

Fig. 2 – Example solar parking structure (SPS). [4]

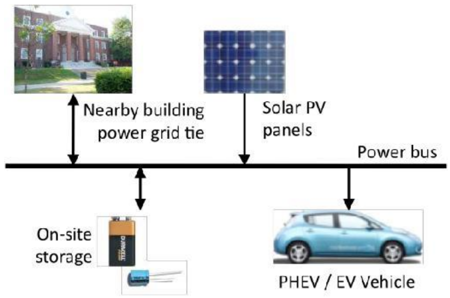

Fig. 3 – Power flows in the SPS

Solar insolation site survey

The potential location for this SPS is the University of Louisville in Louisville, KY. The solar resource has been evaluated using the National Renewable Energy Laboratory's PVWatts [9] software, version 1, for a 10kW DC PV system in Fig. 4. The default parameters, e.g. 77% DC to AC conversion factor, are used for a fixed-tilt system as would be expected for a parking structure roof.

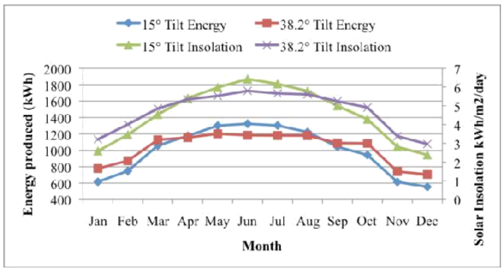

Fig. 4 – Annual solar resource for Louisville, KY.

Louisville, KY is located in the northern hemisphere at approximately 38.2° north latitude. The parking structure is assumed to face south and while latitude tilt is suggested as optimal, lower tilts, such as 15° tilt, still produce 96.7% of the annualized potential power and even exceed this for some Summer months when grid demand is high, also shown in Fig. 4. This indicates a wide range of roof pitches from 15° tilt through 38.2° tilt would function well producing approximately 11,906kWh to 12,308kWh annually.

Strategy of operation

Potential users of the SPS will be students, faculty, and staff at the University of Louisville with PEVs that opt into the program. They will be given a dedicated parking space and charging energy for a flat annual fee.

The SPS is designed to primarily provide clean solar electricity for charging PEV. While it is anticipated that there is insufficient solar energy to fully charge the PEVs over the course of a day, the goal is to at least offset the energy used for the morning commute in so that the vehicle is ready for the evening commute home. The average user's commute is 15 miles to the university, which approximately equates to 3.75kWh of energy using the EPA LA4 test cycle for a Nissan Leaf. If there is excess solar energy, that power can be used to further charge the PEVs, charge the on-site battery, and/or sent to the power grid via a nearby building grid connection. If there is insufficient solar energy for charging the PEVs, energy can be taken from the on-site battery and/or the power grid.
Intelligent power management will be utilized to make decisions on PEV charging, battery charge/discharge, and power grid charge/discharge, in addition to prioritizing each vehicle, as in Tables 1, 2, and Eq. 1. The power management strategy will include demand response based on utility signals to provide further benefits to the power grid. This will be discussed in more detail in sections 3 and 4.

Table 1 – Demand Response Strategies

DR level	Example operating guidelines
Low	Free grid use and full charging. Grid and solar charging of both PEVs and the on-site battery to 100% SOC.
Medium	Grid and solar charging of PEVs by priority to a 3.75kWh target and on-site battery to 60% SOC.
High	No grid consumption. Solar charging of PEVs by priority to a 3.75kWh target with use of the on-site battery if necessary to 20% SOC to meet the PEV target.
Critical	No grid consumption. No PEV charging. Solar power to the grid and battery discharge to the grid down to 20% SOC.

Table 2 – Individual PEV Prioritization

Factor	Notes
Time (t)	The longer a PEV is parked in the SPS, the higher its priority for charging.
SOC (%)	As the PEV approaches 80% SOC, the lower its priority for charging.
Energy (E)	The more energy (total power) a PEV consumes, the lower its priority for charging.

$$P_i = k_t\, t_i + k_{SOC}\,(80\% - SOC_i\,) - k_E\, E_i \qquad \text{Eq. 1}$$

where ***P*** is priority, ***i*** is the vehicle number, ***t*** is time, ***SOC*** is state of charge, ***E*** is energy consumed and ***k*** are the respective tuning constants.

3. MODEL AND SIMULATION

The HOMER [10] simulation software was first explored for simulating the SPS. HOMER is excellent for evaluating multiple system configurations and estimating life cycle costs. In section 2, we have established a fixed configuration based on functional, economic, and physical constraints; therefore different system configurations were not applicable. A grid-connected configuration not utilizing battery storage was used to evaluate the solar resource versus PEV load. Given five vehicles that are each to receive at least 3.75kWh of energy, a total of 18.75kWh per weekday, the net grid consumption was - 6,738kWh/year, a surplus to be supplied back to the grid or used to further charge the PEVs. However, grid purchases were also 1,379kWh/year indicating that at some times, the solar resource was insufficient to supply the PEV load. The on-site battery allows participation in DR given that the battery can be charged from the grid during off-peak times and used to supplement PEV charging when solar is insufficient.

A Microsoft Excel® spreadsheet was also used for simulation to provide an hourly accounting of energy in the SPS, based on the strategies of Tables 1 and 2. These strategies are realized as a rule-based expert calculation, shown in Fig. 5, driven by the demand response level to determine the power flow, as in Fig. 3. A set of IF-THEN

4. CONCLUSIONS

Solar photovoltaic parking structures have been investigated for some time. The inclusion of PEV charging stations to the structure adds shelter for the vehicles and convenience for charging. This project simulates the further inclusion of intelligent power management and on-site power storage to facilitate that management. This novel idea takes the concerns of the grid impacts of PEV charging [1], and turns them into benefits [2] by managing the PEVs together with demand response and on-site power storage. The educational and research components allow the state of the art to be advanced further while training the next generation of renewable energy and power grid personnel.

Benefits of on-site battery storage

Inclusion of a sufficiently sized battery would reduce this shortfall by shifting the demand on a daily basis. A 24kWh battery would be sufficient to supply enough energy for the five PEVs to offset their morning commute. Solar energy could be used to further charge the PEVs, reduce load on the battery, or fed back to the grid as dictated by the expert system. A grid connection is still required since much of the shortfall occurs in the winter months and the on-site battery would still need to be charged the night before to start each day with a full charge.

- Allows PEV charging to be coordinated by demand response without utilizing the PEV batteries directly.
- Aggregates multiple PEVs into a single managed load.
- Serves as both demand side control and distributed power storage.
- Educational aspects discussed in section 4.3.

Environmental benefits and cost savings

The power for the solar parking structure comes from the power grid and the solar panels. The carbon dioxide reductions thus come from the use of solar power to offset the power grid demand. From the solar insolation survey in section 2.1, solar power production ranged from 11,906kWh to 12,308kWh annually. This amounted to approximately 27,383lbs to 28,308lbs of carbon dioxide offset relative to coal-based electricity.

Fuel and energy cost savings to users of the parking structure become equivalent to whatever charge their PEV obtains when parked. From the simulation, the PEVs obtained 10,844kWh of energy annually assuming a 1:1 ratio of low and medium DR levels, or 2,169kWh each. At 10¢/kWh, this equates to almost $217 each if the users had charged at home instead, which could be used to offset parking fees. If we assume the city/highway average gasoline equivalent of the typical PEV to be about 25mpg, and the cost of gasoline at about $3.00/gal, the fuel savings to PEVs recouping only their 15 mile commute in would be approximately 150 gallons or $450 for each PEV.

Educational and research aspects of the SPS

In addition to solving the problems of incorporating PEVs into the power grid, another goal of the SPS is to provide a research platform for testing and educational purposes. Some of the potential aspects being investigated are:

- Learning experiences in daily operation and maintenance of such a structure
- Learning experiences in computer science for algorithm development for intelligent power management
- Statistical evaluation of real-world PEV use
- Evaluation prototype solar PV panels
- Evaluating prototype storage technologies, e.g. batteries, super capacitors, etc
- Investigation of environmental and business case scenarios

The SPS allows the above aspects to be investigated in conjunction with existing technologies in a real-world environment. The educational and environmental benefits would likely achieve popular acceptance of the project in mainstream media. Partnerships with local governments, universities, PEV manufacturers, and local utilities provide a wide base of sharing costs, efforts, and benefits to make such a project achievable

REFERENCES

[1] M. Nigris, I. Gianinoni, S. Grillo, S. Massucco, and

F. Silvestro, “Impact Evaluation of Plug-in Electric Vehicles (PEV) on Electric Distribution Networks,”
14th International Conference on Harmonics and Quality of Power (ICHQP), Bergamo, Italy, pp. 1-6, 26-29 Sep 2010.

[2] T. Odun-Ayo and M. Crow, “An Analysis of the Impact of Plug-In Hybrid Electric Vehicles on Power

System Stability,” North American Power Symposium (NAPS), pp. 1-5, 4-6 Oct 2009.

[3] Pike Research LLC, “48% of Consumers Interested in Purchasing a Plug-in Hybrid Electric Vehicle,” press release, Pike Research LLC, Sep 2009.

[4] S. Stegall, “New Solar Charging Station On Campus,” press release Central Florida Future and UCFToday, found at WWW http://today.ucf.edu/new-solar-charging-station-on-campus/, Feb 2010.

[5] Richland LLC, Pulaski, TN, “First Parking Area Solar Array with Electric Vehicle Charging Capacity is Commissioned in an Unlikely Place,” press release, found at WWW http://green.autoblog.com/2010/08/23/solar-parking-lot-with-electric-car-charging-stations-opens-in-t/, Aug 2010.

[6] Lane Community College, Eugene, OR, “Solar Station Project,” press release, found at WWW http://www.lanecc.edu/bond/buildingsolarstation.htm l, Nov 2010.

[7] Nissan Motors, “Nissan LEAF Electric Car,” found at WWW http://www.nissanusa.com/leaf-electric-car/index -/leaf-electric-car/, Nov 2010.

[8] General Motors Company, “2011 Chevy Volt Chevrolet,” found at WWW http://www.chevrolet.com/volt/, Nov 2010.

[9] PVWatts v. 1, National Renewable Energy Laboratory, found at WWW http://rredc.nrel.gov/solar/calculators/PVWATTS/ver sion1/, Nov 2010.

[10] HOMER v. 2.68, Homer Energy, found at WWW http://www.homerenergy.com/, Nov 2010.

BIOGRAPHIES

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