Elements of MicroGrid: Battery Management and Grid Impact Study

Revision: 03/23/2011

Under Tasks 4.0 and 4.2 of Agreement Number 500-09-039 establishing the California Smart Grid Center, we propose several research goals in the study of the impact on the distribution grid of plug-in hybrid and electric vehicles. The goals are centered on the creation of a test bed vehicle that allows research in several areas:

1. Monitoring and control of battery charging with respect to real time grid status. Managing power flow into and out of the battery to simulate microgrid power storage. Charging of the battery is a grid load to be managed. Discharge of the battery can be for moving the vehicle and/or as a grid resource where power flows out of the battery for local energy needs.
2. Integration the electric vehicle use models developed by the UC Davis PH&EV Center and other industry initiatives.
3. Delivering real time vehicle status information. The vehicle user will require status information for their trip planning purposes. The researchers desire battery status data that lead to usable forecasts of energy needs and availability.
4. Integration of this vehicle specific data with other studies of PH&EV vehicles to estimate the impact on the distribution system health and reliability.
5. Incorporation of Demand Response issues into the energy storage/use system.

We envision two simultaneous approaches for these tasks under the CEC grant. The first effort has already begun which is the preparation of a report that outlines the existing body of research knowledge of how P&EV might impact the power distribution grid network including lifecycle issues with typical neighborhood transformers. We have contacted various utilities that will or have already performed relevant research such as SMUD, PG&E and SDG&E. The subtask reports will incorporate publishable data from those sources with a focus on California issues. Studies from activities outside California will include automotive manufacturer information, SAE standards and special interest groups.

At the same time, the research group will create a movable platform with sensors, instrumentation, wireless communication and battery system controls. This vehicle and battery system will allow for scaled model testing under very controlled conditions. The ECS College already owns two Ford Think Neighbor vehicles (golf carts) that appear suitable for retro-fitting the best parts into a single vehicle. This vehicle will need running gear refurbishment and alteration to accommodate the research battery systems. The project will also need batteries, systems to charge the batteries, monitor grid status, communicate the sensor data to off-vehicle data acquisition systems, inverters for battery to grid testing, and a microgrid electrical load such as a mock residence/room. The project will also install and use electrical isolation and connection devices similar to that required for local emergency power generators or other distributed energy supplies such as photovoltaic system. This project will employ grid tie interconnects, disconnects, smart meter monitoring and hopefully make use of any newly installed distributed energy resources.

The listed five goals are only tangential to a moving electric vehicle. However using a vehicle that can move about campus offers the opportunity to create a test bed that partly mimics a highway ready vehicle while tightly controlling the energy use environment. One advantage of the test bed vehicle is it allows testing power flow into and out of the battery system – something production vehicles will expressively prohibit. A campus vehicle will also allow testing battery management scenarios where use of the vehicle depends on the user's perceived immediate needs. And lastly, a moving vehicle is just a wow factor that creates tremendous excitement for the ECS College, the University and the Smart Grid Center.

Timing: Two Years – June 2011 through June 2013

Spring 2011 – Initial literature research and compilation of industry efforts was provided under Task 4.2 and was started in November 2010. Work includes literature search and interviews with utilities, special interest groups and standards agencies; Collaboration with UC Davis PH&EV Center on vehicle use models.

Laboratory research was started in December 2010 with the task of studying high energy batteries and associated power control electronics. Two undergraduate students are working part-time on this research and were able to engage two notable companies with technical assistance, donations and engineering samples. Winston Battery (www.thunder-sky.com) donated a LiFePo battery cell in January 2011and continues to assist us with development of battery management techniques. MicroChip (www.microchip.com) has a focus in smart grid and microcontroller based power management electronics and has agreed to collaborate with the CSGC in this project.

Summer 2011 – Work to begin with funding approval of the project. Tasks: Ford Think vehicle preparation and modification; selection and acquisition of sensors and instrumentation; selection and installation of support devices such as chargers, wireless communication, GIS devices, vehicle "garage" and mock residential room.

Fall 2011 - Continued integration of the various functional elements of the battery management research platform. Functional testing of all vehicle systems to include chargers, instrumentation, wireless systems to verify vehicle test bed ready for control algorithm testing. Develop initial vehicle user interface.   Seek collaboration with smart meter and demand response groups.

Spring 2012 through Spring 2013 – Creation and testing of battery management control algorithms including demand response scenarios, variable user needs, use as an ancillary service and other energy management issues.

Functional Categories: Overview

Battery

The battery system is the main energy storage device in this project. The batteries need to provide energy storage to allow for scaled microgrid research. The total battery capacity, charging/discharging profiles and cell configurations are a central research topic. The team will be agnostic to any specific battery chemistry and energy density but will seek data that attempts to validate industry energy storage trends. Many energy storage methods are beyond the campus' near-term ability to create such as water pumped storage, compressed gas or biofuel production. Thus batteries provide a convenient, scalable, and implementable energy storage capability for this research. The team will perform periodic literature research on battery to grid topics as that field evolves.

Charging of batteries depends on many factors such as temperature of the environment and the battery pack itself including past history of the battery pack (lifecycle degradation) and how quickly the charge must be completed. Sensors and embedded processors will be employed to acquire the battery condition, current status, environmental conditions and other state variables.

Charging Systems/Battery Management

A suitable charger station will be installed in the tech shop to support the vehicle. In the initial stages, a version of the SAE J1772 standard will be implemented with modifications to allow for bilateral power flows from the grid to the battery and out of the battery to the grid. A J1772 compliant charging wand and receptacle was acquired in Spring 2011 and initial testing was accomplished in an undergraduate research project. In later research, the entire battery management system will be one object of the research to include enabling a demand response capability. The power provided to and received from the battery system is one of the important data points. Thus dedicated power monitoring at the main power entry point to the vehicle will be installed. This may be in the form of a smart meter or other power monitoring device with local data storage and communication capability.

Vehicle

The proposed vehicle is one of the battery powered Ford Think Neighbor "golf carts" already owned by the ECS College. There are two carts and both may need to be cannibalized for parts to create one fully functional vehicle. Where possible the existing vehicle systems will be used and augmented with new batteries, charging systems and instrumentation relevant to the research goals. Jim Ster of the tech shop has stated that he will fully support the effort to include dedicated shop space for the vehicle, and staff assistance in modifying the vehicle as required. His shop staff will be the initial user of the vehicle and will help develop an anticipated use profile of the vehicle. Preferably the vehicle will be available on a checkout basis for routine trips around the campus by ECS College personnel to better determine potential user profiles.

The vehicle will be modified to allow for swapping out candidate battery packs, and the necessary racks, weather enclosures and devices envisioned.

Instrumentation

A primary goal of the research is to monitor the energy flow of the vehicle batteries at all times whether in the shop or out touring the campus. The vehicle will be configured with sensors and systems that acquire this energy data along with relevant environmental factors. LAN/IT devices will be needed to communicate near real time data collection whether the vehicle is parked or roving. In the team's opinion, wireless technologies are a central enabler in many smart grid activities. Allowing the batteries to move will allow for investigation into the use of various wireless systems in the limited campus geographical area. In later work, the vehicle status will become part of a two way communication between the vehicle and the vehicle user to implement dynamic control strategies.

The vehicle and the battery management system will be monitored 24 hours a day and that data recorded in near real time on the energy data servers. The infrastructure for this energy data storage was implemented in Fall 2010 with the purchase and installation of 5 TBytes of hard disk storage, and various wired and wireless LAN devices to create a research VPN mostly segregated from the ECS daily operations. OSIsoft donated a research license for the Pi database software in Fall 2010 and the software was installed. Students are receiving training in the use of this high-end software. Other companies such as IBM have also shown interest in our research and the team will investigate other large data set analysis tools. This energy flow information will form the basis for a profile that details the battery charging/discharging lifecycle use on control algorithm development.

A sensor/home area network focused CSGC laboratory was created in Fall 2010. The team wishes to leverage the Building to Grid and HAN activities of that lab in the vehicle sensor and data acquisition efforts. Critical skills from that lab include low power sensor/wireless operation, techniques in environmental data gathering, data tagging, microcontroller integration, and other instrumentation techniques. In the sensor lab, experience is being gained in use of National Instrument's LabVIEW, Mathwork's Simulink and Matlab, as well as other platform specific software tools. That experience should transport effectively to this energy management project.

Power Electronics

A central technology employment in this project will be voltage conversion including dc to dc, ac to dc and dc to ac. Power from the grid up to 480 Vac will need conversion from ac to dc for charging the batteries. A renewable energy resource may generate ac as in wind power. Other resources may generate a dc voltage as in photovoltaic panels. Whatever the power source the voltage and current from that source must be matched to the requirements of the energy storage device which is typically a battery. Most of the individual battery cells are in the 3 to 5 maximum volt range with operating voltages ranging usually from 2 to 4 volts. The cells are configured into arrays of series and parallels modules. The series arrays add up the cell voltages to some desired level. The parallel arrays allow for increased current flow at some specified voltage. The charging and discharging procedures vary by battery chemistry and specific battery module. So the study and potential creation a flexible set of systems that converts from an arbitrary voltage whether ac or dc to some also arbitrary dc voltage will be significant effort in the project.

The load that is connected to the energy storage device can also vary. This project will examine the vehicle load which includes primary propulsion motors and various control circuitry and vehicle driver systems. Most likely, the team will employ dc boost circuits to raise the battery voltages to that required by the vehicle drive motors. DC buck circuits may also be used to provide power to instrumentation and vehicle controls. The project will also provide power to a small scale "business office" with loads like computers, lighting, heaters and similar devices. Thus the project will employ inverters that accept the batteries' dc power and convert that power to single-phase ac power.

Control Development

The user of the vehicle should normally be able to climb in and drive without consideration of the underlying grid status. Successful development of control algorithms that take the acquired vehicle state variables, grid status, and anticipated user demands into account and allow the vehicle user to "just drive" will be the end goal of the project. Both the instrumentation and control algorithm development is a fruitful area for collaboration with other tasks with the grant, with other CEC designated Centers, other universities, and device vendors. With this in mind, the demonstration portion of the task should reflect a wider view than just the "golf cart" control algorithm.

Relevant sections of the grant document:

Task 4.0 Smart Grid Demonstrations
The goal of this task is to develop demonstration test beds in the following areas--- including Plug-in Hybrid and Electric Vehicles (PH&EV)

Deliverables: Annual Subtask Report and Participate in the TAC meetings. Next subtask report due 12/15/2011.

Task 4.2 Plug-in Hybrid and Electric Vehicles (PH&EV)
The goal of this task is to demonstrate the integration of PH&EVs in[to] the California smart grid.

1. Conduct a literature search on PH&EV issues associated with use [i.e. impact of the vehicles] on the distribution system.
2. Work with the UC Davis PH&EV Center and California Utilities to identify additional issues associated with PH&EV use at the distribution level [of the power grid].

Deliverables: Prepare a subtask report documenting the identified issues. Subtask report will include scope of work and budgets for following years. This proposal is a significant part of the scope of work and budgets. Next subtask report due 4/15/2011.