Community Energy Storage with Secondary Use EV/PHEV Batteries

M. Starke*, P. Irminger*, B. Ollis*, G. Andrews*, O. Onar*, P. Karlson**, S. Thambiappah**, P. Valencia**, S. Massin***, A. Goodson***, P. Rosenfeld***.

*Oak Ridge National Laboratory, One Bethel Valley Rd, Oak Ridge TN 37831, starkemr@ornl.gov
**General Motors Company, 3000 Van Dyke Ave, Warren MI 48090, pablo.valencia@gm.com
***ABB, 655 Century Pt, Lake Mary FL 32746, alexandra.l.goodson@us.abb.com

ABSTRACT

This study presents the design and testing of a community energy storage (CES) system composed of repurposed used electric or plug-in hybrid electric vehicle (EV/PHEV) battery packs. Community energy storage systems can be a feasible application of these second use vehicle batteries. These batteries, if their power electronic interfaces are controlled properly, can perform many grid support applications.

Keywords: energy storage, secondary-use batteries, electric vehicle batteries, plug-in electric vehicle batteries

1 INTRODUCTION

A key issue for energy storage to reach mass-market power grid acceptance has often been associated with cost[1]-[2]. When examining single cost scenarios for energy storage systems, there are very few specific grid applications where the cost to benefit ratio appear to drive the necessary motivation for investment. In a study completed in 2011, single and synergistic benefits were examined for secondary use battery applications and a number of applications where energy storage will most likely fill a role were proposed [3]. The term "secondary-use" in relation to battery technologies refers to batteries previously utilized in electric vehicles, but have outlived the vehicle.

Growing interest has appeared in the concept of applying these secondary use batteries in a distributed sense in conjunction with the smart grid. By distributing energy storage along many locations, these units could provide the same benefits as a centralized unit but with potentially more localized applications. Community energy storage is an example of such a system and has been described to have benefits that target shifting renewable generation and load peaks, providing uninterruptable power, local reactive power support, and grid services when aggregated with many units.

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This paper discusses the design and testing of a secondary-use community energy storage with collaboration between (ABB), General Motors (GM), and Oak Ridge National Laboratory (ORNL). This paper will discuss the design elements, initial control and application development, as well as initial testing results.

2 BACKGROUND

A community energy storage (CES) system is an energy storage system that is utilized between several residential homes and the transformer connecting the homes to the distribution feeder to buffer the distribution feeder from potential impact of renewable resources as well as new larger loads such as PHEV (plug-in electric vehicle) and EVs (electric vehicles) as shown in Figure 1. As shown, an isolation switch is also present to sustain the residential homes for a short period during a system outage. These energy storage systems have been generally slated to the size of 25kW with 50kWh of energy storage and can supply between 2 and 5 homes depending on the aggregated load of the combined homes [4]. The driving motivation in examining this particular application is that the distributed nature of these storage systems provides an opportunity to tackle multiple applications and maximize the economic value.

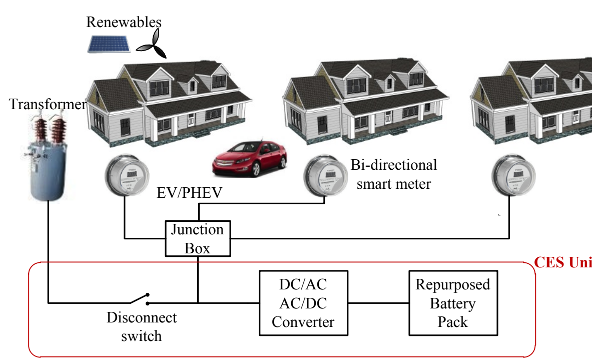

Figure 1: CES unit supplying three homes.

As a result of the location of these storage systems, there are a number of different applications that the storage system can supply both locally for distribution and in aggregation to transmission:

- *Electric energy time shift/ Time-of-use energy cost management:* On an aggregated scale, the units can store the needed energy at night created by generation and deliver this energy during peak periods of energy consumption at homes.
- *Service reliability:* With several hours of back-up power and a disconnection switch, the CES is able to continue providing power to the homes in islanding mode during utility outage.
- *Firming and shifting renewables:* The CES is able to behave as a buffer between the utility and renewables by absorbing excess energy from the renewables and deliver energy during period of shortage and removing high frequency oscillations.
- *Ancillary Service applications:* The energy storage system can supply the local load on an aggregated scale with a ramping behavior that appears as ancillary services such as frequency regulation and spinning.
- *T&D upgrade deferral:* Substation and other system equipment may not have to be upgraded even with the addition of PHEV and load increase due to the ability to supply energy during peak periods.
- *Voltage support:* Internal inverter that interconnects the low voltage AC to the DC bus for the batteries can be controlled to dynamically provide reactive power support and adjust power factor.

3 SYSTEM DESIGN

A schematic diagram of the secondary-use commmunity energy storage (CES) system is shown in Figure 2. The system has a single phase connection with the grid which is protected by an AC breaker (Zone 1). The inverter connects the grid with the battery system and controls the charging and discharging (Zone 2). The battery system connects with the inverter (Zone 3), is composed of five battery strings, and is controlled by a battery management system (BMS). The BMS measures the voltage, current and temperature from the battery systems and communicates with the inverter control to achieve a controlled charge and discharge. The system has a series of safety interlocks which prevent an unsafe access to the unit (Zone 4). The thermal management system is composed of fans and heaters in the inverter enclosure and a separate HVAC unit in the battery enclosure (Zone 5).

In addition to the filtering functionality included in the inverter, the active filter can also provide reactive power compensation. In contrast to traditional capacitor banks, the PQF's reactive compensation is continuous (stepless), fast and smooth since there are no transients at switching. Depending on the load type, the compensation can be either capacitive or inductive.

The inverter offers two types of compensation automatic and fixed. Automatic compensation requires a target power factor to set while fixed compensation is based on a pre-determined amount of kVar. The user is able to select and program which compensation is required, independently of the harmonic filtering. The only limitation is the active filter rating. In operating the inverter, the use reactive power of limits the current output capability of the filter.

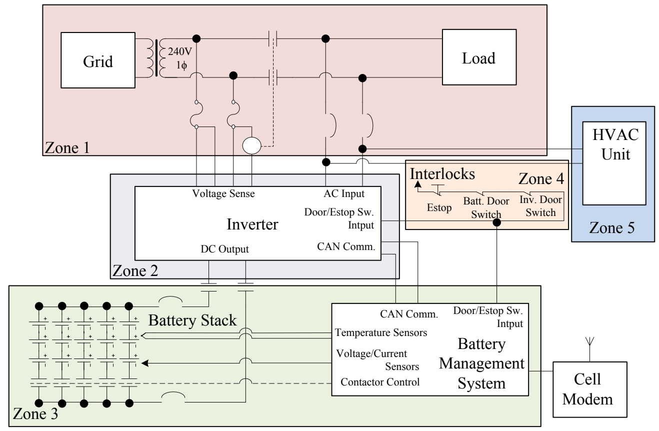

Figure 2: CES configuration.

The battery system consists of 5 repurposed Chevrolet Volt battery packs and a Battery Management System (BMS), which monitors and controls all of the battery system functions. The Volt battery pack in its vehicle configuration is shown in Figure 3 as pictured the cells are physically organized in three discrete 'sections' within the T-shaped pack. For the purposes more efficient packing in the CES unit, the battery sections were repackaged in the manner shown in Figure 4.

The Battery Management System (BMS) consists of a hierarchy of electronic controllers and sensors, which combined, monitor all critical battery parameters, control and enforce limits on battery operation and act as a single point interface to the inverter system. In addition, the BMS calculates key battery states (i.e. state of charge, charge/discharge power limits) and communicates these to the grid control system via the inverter.

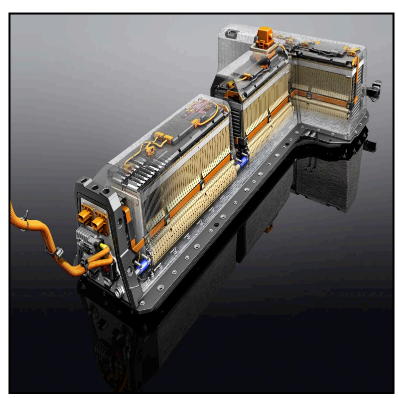

Figure 3: Volt battery pack in vehicle configuration.

The CES system is interconnected in the ORNL distribution system and DECC (Distributed Energy, Communication, and Control) facility as shown in Figure 5.

A 37.5kVA, 480V/240V split phase transformer supplies the community energy storage system with grid interconnectionand a NHR programmable load bank is provided to test various discharge and charge profiles. An automatic disconnect switch has been put in series with the step-down transformer for the testing of islanding functionality. Manual disconnects have been put in place to isolate the energy storage system for safety. Photovoltaics are also integrated to demonstrate different renewable integration options with energy storage.

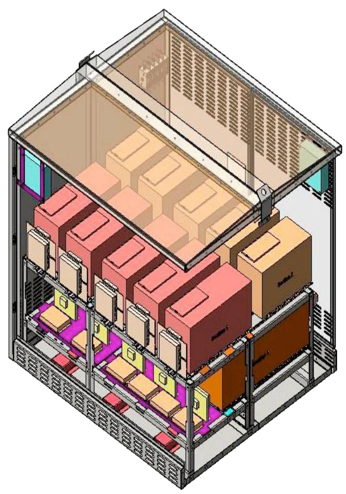

Figure 4: Integrated battery bank for energy storage system.

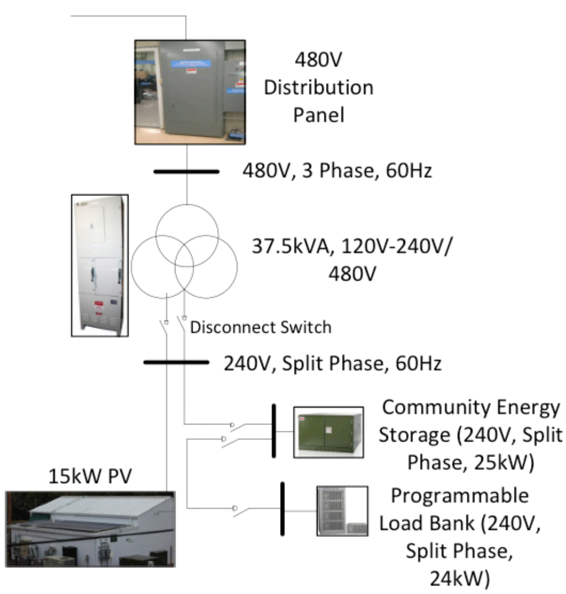

Figure 5: Grid interconnection

Matlab is used to interface all of the hardware and communication for the system testing configuration. Modbus protocols were developed to both read and write the ABB PQF link through a RS232 over RS485 communications link. The load bank is controlled through a direct serial connection as shown in Figure 6 with software provided by NH Research. These measurements were collected by a National Instruments Compact Rio field-programmable gate array (FPGA) running Labview software.

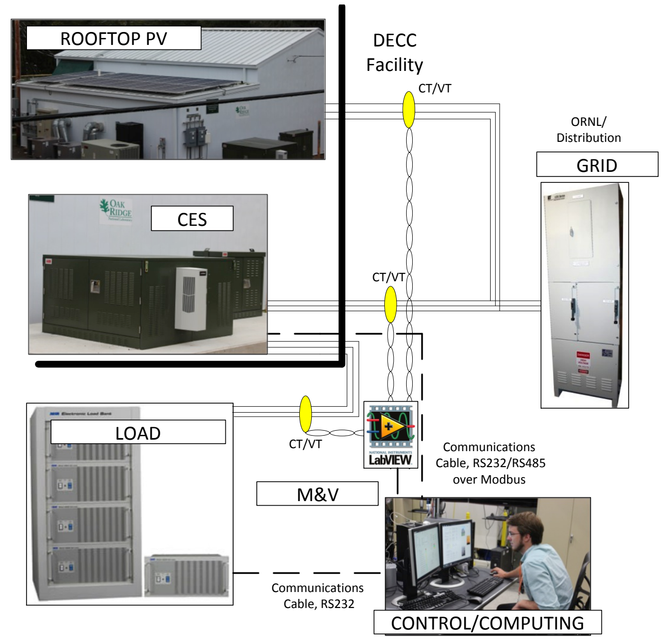

Figure 6: Communication and Hardware

Separate functions were imbedded in Matlab to control the CES to perform various grid applications. The programmable load was controlled to mimic residential load consumption based on work performed in [5]-[6]. Forecasted weather and irradiance measurements were used to develop these residential profiles on a daily basis to best link the relationship between residential consumption, energy storage utilization, and thermal management.

4 TESTING AND RESULTS

The testing protocols discussed here consist of load flattening for T&D deferal, solar integration, and islanding. Other capabilities are also available and are being tested. The testing has been performed over a period of several months and is continuing.

Figure 8 shows an example test run demonstrating the ability of the storage system to provide T&D deferal. A three home residential load profile was created and programmed on the load bank. A genetic algorithm was utilized to optimize the flattening of the load through the use of the energy storage system. In this example, the residential peak is reduced by over 50%.

Figure 9 shows an example of solar integration. A PV forecast was created so that the energy storage system could enforce this forecast even as the solar output of the PV on the rooftop of the DECC facility produced intermittent output due to cloud cover. The intermittency is a

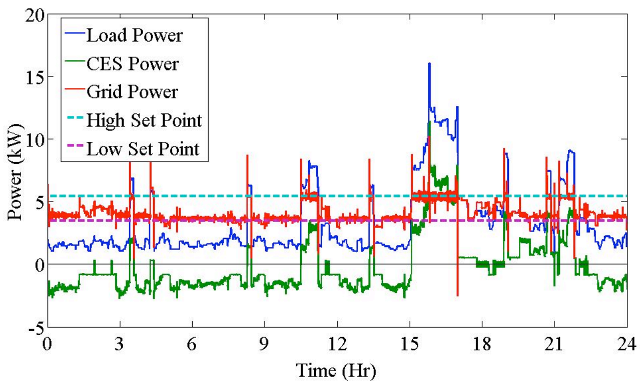

Figure 8: Load flattening example.

distribution system challenge. Upstream transformers, as an example, may be forced to perform a significant number of increased tap changes to ensure system voltage is maintained. This could cause higher O&M costs while still not completely stabilizing the line voltage.

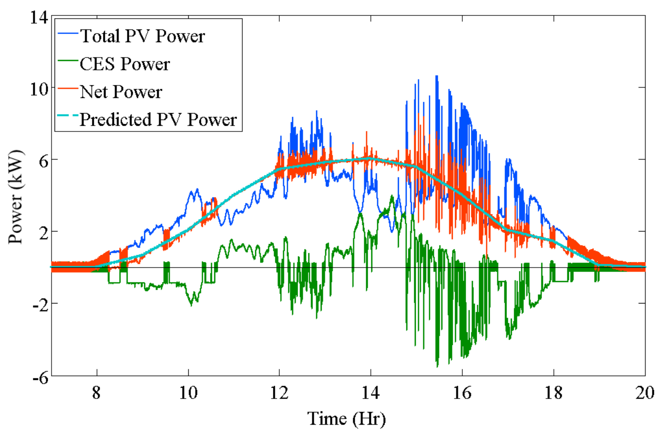

Figure 9: PV integration example.

Figure 10 shows the use of the storage to go 'off-grid' and reconnect to the grid. A residential load profile is used to demonstrate that the CES is able to follow the needed load power.

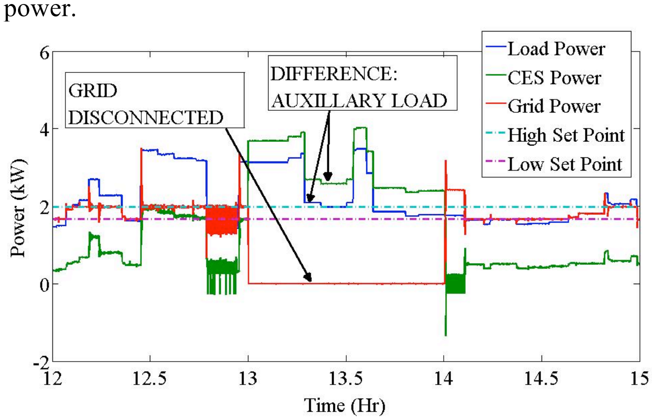

Figure 10: Energy storage entering and reconnecting to distribution from island mode.

5 CONCLUSION AND FUTURE WORK

In this paper, the ability of secondary use storage systems to perform the same functions as a new battery system at a potentially lower cost has been demonstrated. The algorithms needed to perform different energy storage functions have been demonstrated with measured results shown.

Future work will focus on developing multi-objective functions that will lead increased value propositions for energy storage systems.

6 ACKNOWLEDGEMENTS

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