A Battery Storage System for Distributed Demand Response in Rural Environments

Roy McCann (University of Arkansas; Fayetteville, Arkansas, USA; rmccann@uark.edu)
Robert Winkelman (LGW Incorporated); David Moody (LGW Incorporated)

Abstract – This paper presents the results of deploying three sets of 75 kWh battery distributed energy storage (BDES) systems at residences located in Binger, Oklahoma and Fayetteville, Arkansas. In addition, a commercial facility installation has been brought on-line. These sites include renewable energy generation consisting of a residential 450W solar photovoltaic source and a 65 kW wind turbine at the commercial facility. The BDES system was developed in collaboration with the University of Arkansas and deployed with assistance from Caddo Electric Cooperative (Oklahoma) and Ozarks Electric Cooperative (Arkansas). Results confirm the expected benefits of battery distributed energy storage systems for demand response management.

Introduction

Distributed energy systems have received considerable recent attention due to increasing use of renewable energy sources such as wind and solar. This implies a departure from traditional electric power transmission-distribution architectures and topologies. In addition, the inclusion of nondispatchable energy sources presents difficulties in terms of integrating these electrical sources with existing electrical generation. Conventionally, large centrally located electric generating stations provide power for the surrounding region. In the event of mismatches between local load demand and generation supply, regional system operators may facilitate electric power flows through a transmission service area in order to maximum system stability and security margins while also optimizing operating costs. During peak load demands, market prices change according to incremental costs for peaking units that might be deployed.

Renewable Energy

The introduction of renewable energy sources has many potential advantages. This includes reduced reliance upon imported fuels, as well as potentially reduced consumption of coal and other fossil fuels, thereby reducing the adverse environmental impact associated which such fuel sources. However, renewable energy sources also have a number of disadvantages. Chief among those are increased cost given the state of current technological development. It should be noted that even if there are breakthrough technologies that allow for renewable energy costs to achieve parity with fossil fuels, there remain a number of significant operational challenges that presently hold back the deployment of renewable energy. Of primary concern is that wind and solar sources are intermittent in availability, and therefore are nondispatchable. In the case of solar photovoltaic, electric power availability varies with time of day along with seasonal variations. Ambient temperature variations also impact photovoltaic power availability in that silicon and other semiconductor type materials have reduced output capacity as junction temperature rise. In addition, electrical output of photovoltaics varies with solar insolation intensity. Sporadic cloud cover can result in power fluctuations between 100% and 10% in a matter of minutes. Although not as extreme, similar power fluctuations are encountered with wind generation. In order to provide a satisfactory level of power delivery to supply customer loads, it is necessary that provisions be made to supply electrical power from other sources in order to make up for the shortfalls associated with wind and solar generation.

Integration of Renewables

There are generally three options available in order to alleviate the transient shortfalls encountered with wind and solar sources. The first is through having in standby conventional power sources with control capability to rapidly compensate wind and solar supply transients. This approach is costly in that excess capacity is brought on-line. Moreover, it is difficult to achieve in practice the required level of power tracking capability due to the limited response time of conventional generators to power flow transients. Overall, this approach further penalizes wind and solar resources by adding increased operating expenses.

Demand Response: A second approach is for the local utility provider to aggressively pursue demand response management programs. This potentially allows for automatic load shedding in the event of a sudden decrease in wind and solar capacity. Although this approach may overcome the operating costs associated with conventional standby reserves, it nevertheless will accrue a financial burden upon the utility provider in that incentives will be needed in order for significant customer adoption of demand response programs.

Energy Storage: A third approach is to include energy storage capacity into the local distribution system which provides a buffer to fluctuations in wind and solar supplies. This approach has many advantages over the first two options. The principle of operation is that during times when there is excess wind and solar capacity, the energy storage technology harvests this surplus. Depending upon the particular technology adopted, the energy storage equipment may also be replenished from conventional resources. This paper examines the use of a newly formulated lead-acid battery for distributed energy storage (DER). In this case, the batteries can be charged not only from the wind and solar sources, but also from conventional base-load generation during off-peak times when the marginal production cost is at a minimum. The battery equipment is connected to the electric utility grid through power electronic inverter circuits. This provides remote electronic control of the charge-discharge levels and timing of the battery system. Thus, when there is a decrease in the wind or solar availability, then the battery DES system is discharged to provide continuous service to customer loads.

Distributed Energy

The battery distributed energy storage (BDES) system provides many additional benefits beyond augmentation of intermittent renewable energy capacity. During peak demand periods, the BDES is a dispatchable power source that can be called upon in lieu of peaking units. This avoids the higher operating costs associated with diesel and small gas turbines since the BDES is already installed. In a region where there is a well established base generation capacity, there is often a large variation of incremental fuel and operating costs between peak and minimum load levels. The BDES can be charged during off-peak time, for example between midnight and 6:00am, which also overlaps when wind energy is most abundant. During the following afternoon peak, the battery system can be discharged in response to utility commands, thereby achieving the benefits of demand response initiatives with the advantage of no loss in revenue to the utility company since the batteries are charged during off-peak times from the utility generation.

Rural Electric Challenges: Challenges for rural electric power systems include recurring outages due to storm damage, difficulty in voltage regulation and large load fluctuations associated with agricultural equipment and irrigation systems over low density networks covering large geographical areas. There has been considerable research in the integration of electric utility communication protocols with customers in real-time to coordinate loads for peak-shaving and load-leveling [1]. The adoption of distributed energy sources has further encouraged the investigation of advanced demand response (DR) systems [2]. Much of the published work in this area has been with respect to analysis of historical usage profiles [3]. The contribution of this pilot study is the development of a distributed demand response (DDR) system where an electric utility has the ability to schedule in 15 minute intervals the maximum load level for a particular customer. The BDES system is implemented with an IEEE 1547 compliant grid-tie power electronic inverter [4]-[5] and a 75 kWh lead acid battery storage system that can meet customer demand for loads that exceed the utility DDR set-point. Commands and feedback between the utility and the BDES system is over a Cooper-Cannon PowerLine communication link. Included in the BDES functionality is coordination with the utility service provider to signal preferred times for recharging the battery bank during off-peak times [6].

The potential benefits of implementing a distributed demand response (DDR) system were examined for circumstances encountered in rural environments. The benefits of BDES systems potentially include:

- Ability to manage peak load
- Improved electric service reliability
- Provide for renewable energy integration
- Improve voltage regulation by adjusting reactive power support

Battery Technology: A critical element to the success of BDES systems is the battery technology. Lead acid batteries were selected due to low cost and robustness to environmental conditions. By properly accounting for conditions at the site location, the battery configuration can be optimized to provide sufficient reserve capacity for the anticipated temperature and humidity variations. A novel battery formulation has been developed by the authors which increases the porosity of Pb/PbO_2 plates beyond that achieved with conventional tribasic and tetrabasic lead oxides. Lead normally grows in needle shaped crystals with secondary and tertiary branches. Novel curing and soaking processes have been found to produce octahedral and dodecahedron crystals that have both improved electrochemical porosity with high anode/cathode plate densities. This processing technology achieves approximately 16% increased reserve capacity for a given battery mass/volume metric. Lead acid battery technologies are attractive economically because of the nature of lead mining production and processing. In particular, purified Pb ore is the principle capital investment in lead acid battery systems. Given that reprocessing recovers over 98% of the Pb/PbO_2 material, the capital investment in a lead acid battery installation is a one-time expense that depending on commodity prices may in some cases become an investment for the BDES system owner. Consequently, the financing of $PbSO_4$ batteries can be achieving in various means. One option would be for the BDES system vendor to retain ownership of the Pb/PbO_2 with lease options made to the utility company for use of the inverter and other related components. Alternatively, the utility my exercise an option to own the Pb/PbO_2 material and provide the BDES as part of a service contract. This arrangement overcomes one of the principle challenges in deploying alternative energy systems in terms of the cost implications for utility and end-users/customers wishing to employ energy storage systems.

Pilot Study

BDES systems were deployed at three locations. In this pilot, the three installation sites generally were operated with 12 kW discharge during the peak daily load times of 2:00-8:00pm. Battery charging occurred during off-peak times when marginal electricity rates are lowered. Operational data collected remotely from the pilot installations can be viewed online at http://www.lgwenergynow.com with real-time updates. The pilot site locations and results are described in the following sections. A diagram showing the general configuration is given in Fig. 1. There is a power-line carrier communication link between the utility and the BDES. In response to signals from the utility, the inverter charges, discharges or takes off-line the BDES system. The BDES electrical connection is made at the customer side of the meter. A net-metering agreement is established at each location such that there is an allowance for the BDES system to supply power back into the utility service line. Current and voltage sensors monitor the building loads in order to execute the demand response commands from the utility dispatch center.

Residence: Binger, OK: This pilot site was selected in consultation with Caddo Electric (Oklahoma). Caddo is a rural electric cooperative. Many of their customers install back-up generators due to periodic storm induced outages. Consideration of a BDES system would ordinarily be considered based on its cost competitiveness with natural gas or propane fueled generators. It is difficult to justify the adoption of a BDES system based solely upon this comparison. For the circumstances for Caddo Electric there is a large generation cost differential between nighttime and mid-afternoon peaks that is substantial enough to warrant customer incentives. A 7.5 kW (12 kW peak) inverter with 75 kWh batteries was installed. Power levels are monitored at 15 minute intervals with updates to the power to be delivered by the batteries. During the July peak demand period, the BDES system was generally commanded to deliver 7 kW during a time window of 2:00pm to 6:00pm. The batteries would then be recharged through the bidirectional grid-tie inverter system during the minimum load period between midnight and 6:00am. A representative plot showing the utility load versus BDES supplied power during an afternoon peak is given in Figure 2.

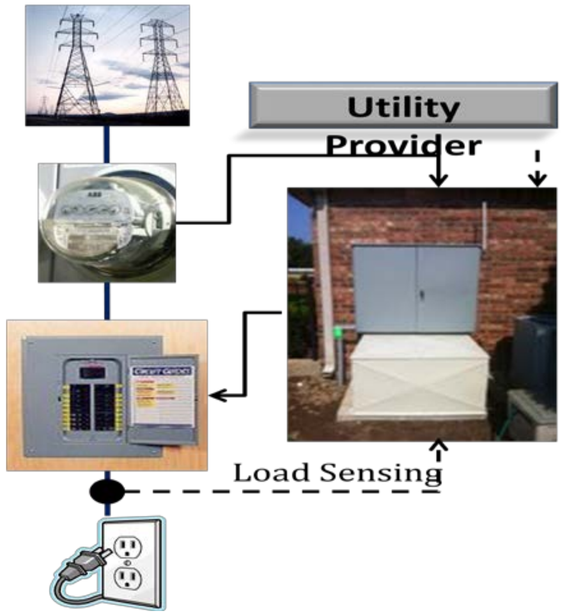

Figure 1: BDES installation configuration.

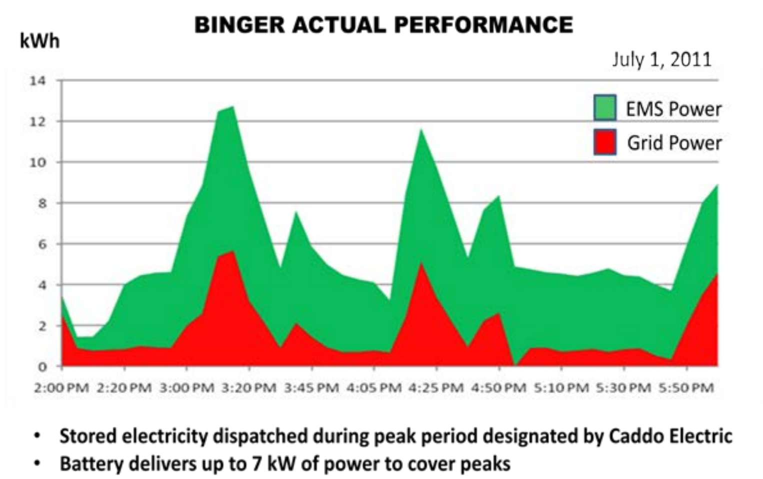

Figure 2: Binger site power profile between 2:00pm and 6:00pm.

Residence: Farmington AR: This is a residential site in the Ozarks Electric (Arkansas) service area. It was selected because of a 450 W solar photovoltaic system had recently been installed. The load profile for many residences during weekdays has a peak that occurs 3:00pm to 8:00pm. This occurs after the peak summer solar insolation of 11:00am to 3:00pm. Thus a site that would demonstrate the effectiveness of a battery storage when combined with solar energy was selected. The BDES system is similar to that shown in Fig. 1 except for the addition of a solar peak power tracker that connects to the dc bus side of the grid-tie inverter. Instrumentation is included to monitor and record solar power production and to include this in executing demand response commands from the utility company. Fig. 3 shows a representative solar power production profile that reaches zero after 5:30pm. Subsequently, a demand response command is received, and the BDES system begins to produce power as shown in Fig. 4. Beginning at 8:00pm, the BDES system begins to recharge the batteries in response to signals from the utility that rate levels have dropped, thereby providing an incentive to maintain load levels for optimize base generation operation.

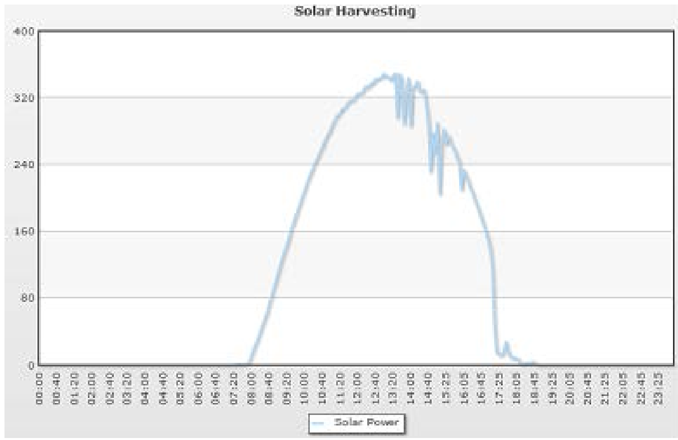

Figure 3: Representative daily solar power production at Prairie Grove site.

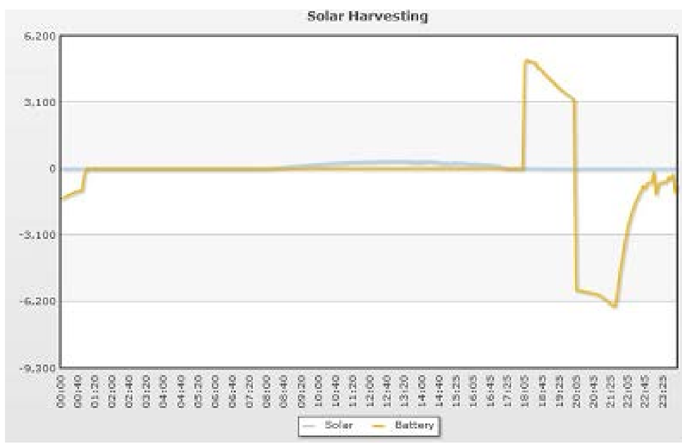

Figure 4: Corresponding BMES power resulting from demand response command.

<u>RCAL Manufacturing Facility, Prairie Grove AR</u>: A commercial facility in the Ozarks Electric service area was identified as a candidate for a BDES system. RCAL is a manufacturer of electronic circuit board assemblies. Electric powered ovens are automatically turned on in early morning hours in order to preheat prior to when operations begin for a 5:00am shift. This results in a poor load factor for the site. With a commercial billing structure in place, the annual billing rate is set largely based on peak recorded demand during a specified summer-time window. Thus, a BDES that would reduce the peak recorded load would have significant impact on annual billing rates. In addition, the RCAL facility has a 65 kW wind turbine that is configured for net-metering. Similarly to the residential installations, power levels from the wind turbine, battery and utility loads are recorded in 15 minute intervals. A representative plot of the utility supplied power and the BDES supplied power is shown in Fig. 5 for the period between 3:00am and 7:00am.

Conclusion

In conclusion, it has been demonstrated that BDES systems are effective in providing improved load management capability in meeting utility load management objectives. The improved integration of wind and solar based sources by providing a dispatchable capability has also been demonstrated. In addition, BDES systems confirm the capability for financial planning [7] by the associated electric utility company for postponing the possible need for adding generation capacity and therefore avoiding large capital expenditures. Commercial facilities with peak-usage billing structure benefit as well as the utility provider in terms of annual planning and forecasting.

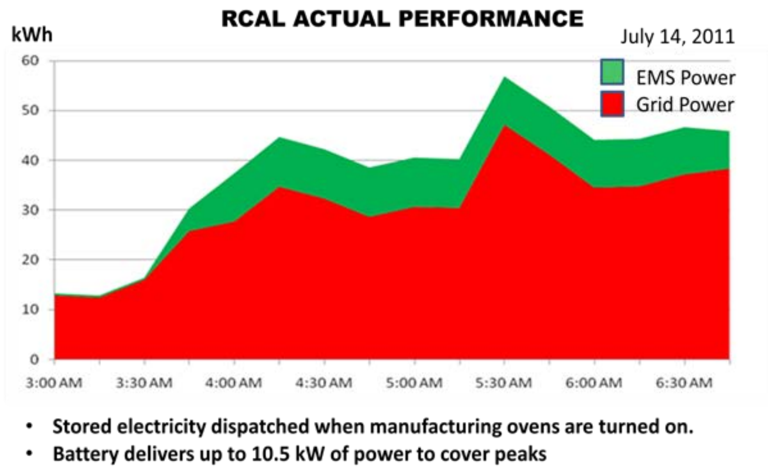

Figure: 5: RCAL facility early morning profile.

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