GRID-CONNECTED SOLAR ENERGY STORAGE USING THE ZINC-BROMINE FLOW BATTERY

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ABSTRACT

The zinc-bromine battery is an emerging energy storage technology, ideally suited for solar load-shifting applications requiring 2 to 10 hours of energy storage. The energy density and cycle life of this advanced battery makes it attractive for applications where conventional lead-acid batteries face limitations due to size, weight, or cycle life.

To test the viability of the zinc-bromine battery for solar applications, two solar photovoltaic (PV)/storage hybrid demonstration projects are currently underway. In the first project, a 50 kW rooftop PV system is being installed in parallel with a 50 kW/100 kWh battery system at a commercial customer facility in New York.

The system is intended to prevent excess PV power from flowing into the utility network that could cause sensitive utility network protectors from tripping off line. The system will be charged by excess PV energy that would otherwise have to be spilled, and it will help to reduce demand charges by discharging stored energy during peak loads.

The second project is a 250 kW/500 kWh utility system that will be installed on a remote utility circuit in New South Wales, Australia. This system will complement an existing 20 kW PV concentrator system, support the remote line, and offer enhanced reliability. The battery will be charged by the solar array during the day in order to provide reliable nighttime power to remote area property owners.

1. THE ZINC-BROMINE BATTERY

The zinc-bromine battery is very different in concept and design from more traditional batteries such as the lead-acid battery. It utilizes a circulation system to continuously feed reactants from external reservoirs into the battery stacks, hence it is classified as a "flowing electrolyte", or flow, battery.

The stack consists of a series of bipolar electrodes and microporous separators between two monopolar (one negative and one positive) terminal electrodes. The bipolar electrodes allow the negative (zinc) reaction and the positive (bromine) reaction to occur on opposite sides of the same electrode.

During charge, zinc is electroplated on the anode and bromine is evolved at the cathode. A complexing agent in the electrolyte is used to reduce the reactivity and vapor pressure of the elemental bromine by forming a polybromide complex. This minimizes the self-discharge of the battery and significantly improves the safety of the system. The complexed bromine is then removed from the stacks via the flowing electrolyte and is stored in the external catholyte reservoir. On discharge, the complexed bromine is returned to the battery stacks, and zinc is oxidized to zinc ions on the anodes, bromine is reduced to bromide ions on the cathodes.

A photograph showing a 25 kW/50 kWh battery module is shown in Figure 1. This identifies the main battery components including electrolyte reservoirs, pumps, stacks, and controls.

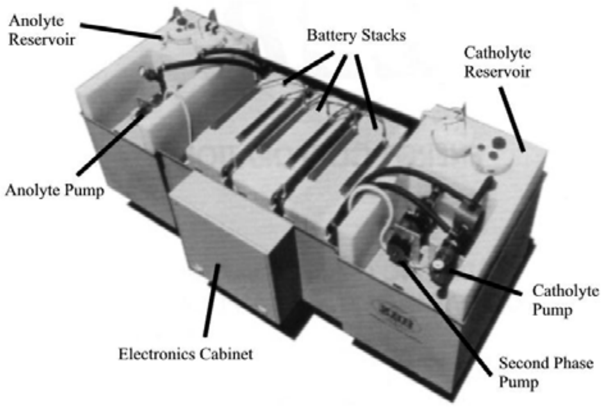

Fig. 1: Zinc-bromine battery module.

This battery concept is relevant to renewable energy applications for three primary reasons. First, unlike most other rechargeable batteries, the zinc-bromine battery uses electrodes that do not take part in the reactions (but merely serve as substrates for the reactions). Consequently, there is no electrode material deterioration that would cause a long term loss of performance from repeated cycling.

Second, the zinc-bromine battery can be completely discharged to 0% state-of-charge (SOC) such that all metallic zinc is dissolved into the electrolyte. In this state, the battery can be left indefinitely with no subsequent loss in performance.

Third, the flowing electrolyte greatly improves the thermal management of the system. Heat generated during the reactions is easily removed from the stacks since the electrolyte acts effectively as a coolant. By keeping the stack temperature within prescribed limits, the stack life is extended significantly.

The zinc-bromine battery stack components are expected to have a life of over 2,000 complete charge-discharge cycles, and it offers 2 to 3 times the energy density (75 to 85 watt-hours per kilogram) with associated size and weight savings over present lead-acid batteries. Detailed descriptions of the zinc-bromine battery have been published previously (1, 2).

2. MODULE CHARACTERISTICS

The building block for large zinc-bromine battery systems is a 50 kWh module, constructed using three 60-cell battery stacks connected in parallel, each having and active cell area of 2500 sq. cm. The module is designed to sustain a 150 amp discharge at an average 96 volts for 4 hours. Module specifications are provided in Table 1.

TABLE 1: 50 KWH MODULE SPECIFICATIONS

	Typical	Maximum
Charge Voltage	112 Volts	126 Volts
Charge Current	150 Amps	
Open Circuit Voltage	109 Volts	
Discharge Current	150 Amps	300 A*
Low Voltage Cutoff	30-60 Volts	
Strip Current Cutoff	1 Amp	

*Two hour discharge rate. The battery is capable of maintaining higher currents.

3. POWER CONDITIONING

Unlike PV inverters, the power conditioning systems (PCS) for batteries integrate supervisory controls to manage power delivery bi-directionally. These system use advanced digital processors to manage the charge and discharge rates of the battery, ensure compliance with utility harmonics standards, and provide protection from anomalies that may be present on either the DC or AC sides.

The PCS is also capable of accepting a wider voltage range of the zinc-bromine battery (to take advantage of the enhanced deep cycle characteristics) and is programmed to manage periodic 100% discharges (“strip cycles”) that further enhance the life of the battery.

4. CUSTOMER DEMONSTRATION (100 KWH)

A 50 kWac rooftop PV system and a 50 kW/100 kWh zinc-bromine battery is being built as a hybrid demonstration at a commercial customer facility in Brooklyn, New York. The storage element is in part intended to help meet protection requirements for interconnecting generation on New York urban electric distribution networks. The hybrid system is scheduled for installation in advance of the summer 2002 peak period.

Without the battery, PV generation exceeding the customer’s load would feed into the utility grid, potentially disrupting the operation of network protectors (shown in Figure 2). Consequently, utilities do not allow generators to export power into these networks.

Load monitors installed at the facility revealed that the minimum daytime weekend load over a two-week period was less than 10 kW. Figure 3 shows the building’s demand profile over a one-week period from Monday through Sunday and a superimposed simulated output of a 50 kWac PV system.

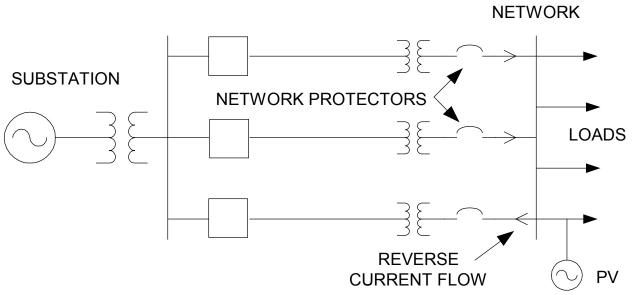

Fig 2: Network distribution system.

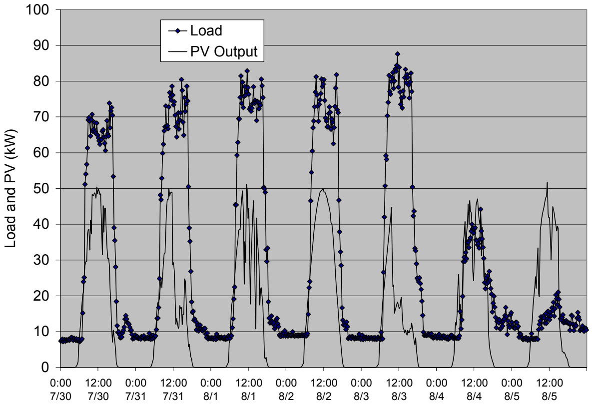

Fig. 3: Daily load profiles and simulated PV output.

The PV output clearly exceeds the loads on weekends and may briefly exceed the load during the early weekday mornings as well. To prevent power flow to the utility, the PV output would have to be curtailed ("spilled") during these critical periods.

The PV/battery hybrid system is designed to overcome this constraint by storing PV energy that would otherwise be spilled and preventing back-flow to the utility. The system will monitor real-time PV production, customer load, and battery SOC and control the battery charging and discharging.

In addition to saving PV energy that would otherwise be lost, the battery will be programmed to discharge during customer peak (weekday) usage, thereby reducing customer demand charges. An advanced control algorithm is being developed for this purpose and will be implemented as part of the demonstration. For redundant utility protection, the system will include a reverse power relay that will disconnect the hybrid system if back-feed is detected.

Figure 4 illustrates the proposed PV and battery system configuration. The PV and battery systems each have their own inverter (isolation transformer not shown), and therefore will be paralleled on the customer AC bus. The 50 kWac PV system will be paralleled with two identical 25 kW/50 kWh batteries (50 kW/100 kWh combined). Since the battery will be able to discharge on weekdays and supplement PV production, the hybrid system can be considered as a 75 or 80 kW peak.

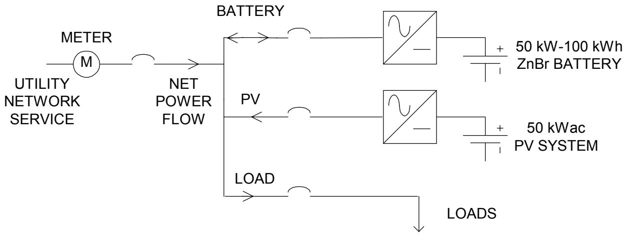

Fig. 4: Hybrid system configuration.

One of two battery/PCS systems built for the project is shown in Figure 5. The cabinet has overall dimensions of 4' (L) x 4' (W) x 7' (H). The inverter is housed on the top shelf, the stacks on the middle shelf, and the electrolyte tanks on the lower shelf. This design allows for a compact installation inside the customer's facility.

Fig. 5: Battery/PCS enclosure with door open.

5. UTILITY DEMONSTRATION (500 KWH)

A second PV storage demonstration system is scheduled to be installed on a remote utility distribution line of

Australian Inland Energy (AIE) in New South Wales, Australia. The storage system will be operated in conjunction with AIE's recently refurbished 20 kW PV concentrator dishes at White Cliffs.

The battery developed for this project is comprised of 10 battery modules, each rated at 50 kWh for a four-hour discharge. Each module will consist of three 60-cell battery stacks connected in parallel, a pair of electrolyte storage reservoirs, and an electrolyte circulation system.

The 10 modules will be housed within two specially-constructed 20-foot shipping containers. The system is designed to sustain a 300-amp discharge at an average 480 volts for 4 hours. The container includes roof-mounted heat exchangers; monitoring equipment; and associated electrical panels. Air conditioning units will most likely be required due to the extreme temperatures anticipated at the White Cliffs site. These air conditioning units will be mounted on the roof of the building.

The system is capable of storing and supplying electricity equivalent to the needs of thirty average households per day. It will be able to store electricity generated by the array of PV concentrating solar dishes, currently under extended testing by AIE. The battery will be charged by the solar dishes during the day in order to provide reliable nighttime power to remote area property owners.

An extensive data collection system has been developed to monitor the battery subsystems. Parasitic losses from the pumps, heat exchanger and control systems can be quantified. A paging system will be installed that will be automatically activated in the event of a fault or shutdown condition.

6. ACKNOWLEDGEMENTS

The authors thank the New York State Energy Research and Development Authority (NYSERDA), Clean Air Communities of New York, the U.S. Department of Energy (DOE), Greenpoint Manufacturing and Design Center (Brooklyn, New York), the Australian Greenhouse Office (AGO), and Australian Inland Energy for providing funding in support of the hybrid system demonstrations.

7. REFERENCES

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