A123's Advanced Grid Storage, Extending Our Experience to Distributed Resource Applications and Microgrids

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ABSTRACT

A123 Systems is a manufacturer of advanced Nanophosphate™ batteries and battery-based systems for commercial, transportation and grid applications. Since 2008, over 36 MW of A123 grid battery systems have been deployed worldwide, based on modular 2 MW building blocks. With support from the U.S. Department of Energy for a Smart Grid Storage Demonstration, A123 will build and deploy smaller 25 kW modular distributed storage systems at a scale and with functionality relevant for local applications, including microgrids.. Today, the superior performance A123's Nanophosphate Advanced Li-ion battery is being used for system level grid-stabilizing functions including frequency regulation. Extensions to A123's existing platform and capabilities will support emerging and advanced distributed resource applications, including microgrids, renewable integration, and active islanding for enhanced customer reliability.

INTRODUCTION

As of late 2010, over 36 MWs of A123 battery-based grid connected energy storage systems have been deployed. These systems use A123's proprietary Nanophosphate™ Li-ion battery chemistry. While this paper focuses on system level applications, a few metrics for the Nanophsophate™ battery help illustrate how the characteristics of this battery enable building kW to multi-MW scale grid storage systems.

Power – at the cell level, A123 batteries can fully discharge and charge at over a 10C rate. 10C rate allows fully charging and discharging within 6 minutes. This rapid rate of charge can be sustained independently of the number of cells assembled in a pack or module.

Safety – the Nanophosphate™ cell releases minimal oxygen when exposed to elevated temperatures, thereby posing lower fire risk relative to other Li-ion chemistries. In an independent report published by Sandia National Labs, E. Peter Roth states, "the significant reduction in cell heating rates for the Nanophosphate material is attributable to the lack of oxygen decomposition from the cathode material." (Roth, 2007) The low fire risk permits reliable, space-efficient configurations.

Life – as measured both in cycles and shelf life, A123 cells show excellent durability. An A123 cylindrical 26650 battery delivers retains 80% of its energy capacity after 8,000 cycles at 1C/1C[1] rate of charge/discharge, and 100% depth of discharge, and exhibits calendar life exceeding 10 years in automotive and grid environments. This endurance allows the cells to survive the heavy duty cycles required in grid applications. Sufficiently long duty life is crucial for economically viable operation as a grid resource. Figure 1 below illustrates the high cycle life capability of the A123's Nanophosphate™ battery.

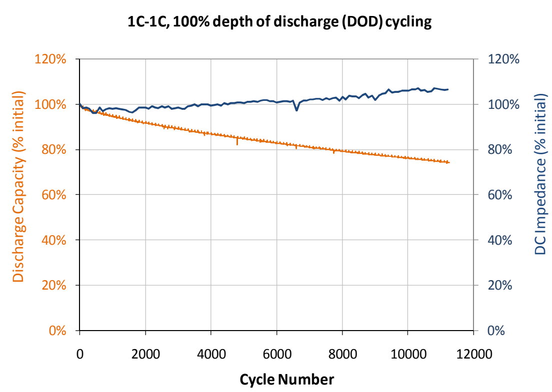

Figure 1
Cycle life of A123 cylindrical cells at 1C charge rate and 100% DoD cycling

These advanced battery characteristics imparting Power, Safety, and Life are ideally suited to provide frequency regulation on power grids. As described below, delivering frequency

[1] Charge and discharge full capacity in one hour

regulation requires the ability to provide and absorb energy in short-duration bursts, which matches the high charge and discharge rate capabilities of the battery.

DISCUSSION

A123's Grid Battery System

Many of the A123 grid systems in commercial service today are owned and operated by A123's developer partner, AES Storage. Recent deployed projects are comprised of multi-unit arrays of A123's modular Grid Battery System (GBS). Figure 2 shows a portion of a 12 MW array of A123's GBS units that AES placed into commercial service in 2009.

Figure 2
12 MW Array of A123 GBS Containers, Commercial Operation, Chile 2009

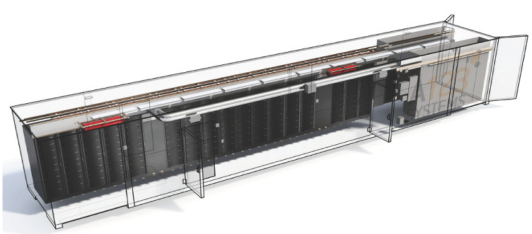

Figure 3
Artist Rendering of a Single GBS Unit

The characteristics and capabilities of the system illustrated in Fig. 3 include:

1) 2 MW power and 500 kWh energy capacity
2) 20ms response time for power output changes in response to control signals
3) System round-trip efficiency near 90%
4) Cycle-life ranging from near 10,000 to multiple 100,000's depending on actual Wh throughput. Wh throughput is proportional to the average depth of discharge per cycle and the number of cycles per time period.

Initial Grid Application, Ancillary Services

A123's GBS based grid systems that have been deployed to-date are used for Frequency Regulation and Spinning Reserves. These are Ancillary Services as defined in the FERC Open Access Transmission Tariff Pro-Forma Tariff (FERC, 1997). Spinning Reserve is a form of back-up where a resource is synchronized to the grid, but does not deliver power unless called upon, typically after a system outage event. Frequency Regulation requires power capacity to be continuously varied across a defined power MW range in response to an Automatic Generator Control (AGC) signal. An AGC signal for a unit performing Frequency Regulation will typically raise and lower the power output in inverse proportion to the deviation of system frequency from a nominal value (60Hz in the U.S.). Since, under normal conditions, electrical grids continuously oscillate bi-directionally 'plus and minus' around the nominal system frequency, this allows implementation of storage-based grid systems (including mechanical as well as battery based grid systems) that exchange energy bi-directionally with the grid frequently enough to remain in continuous service, despite limited energy capacity. Thus, the GBS can effectively provide this service with a power-to-energy ratio of 4:1.

Figure 4 below is a simplified conceptual diagram of moment-to-moment varying power output required when a grid resource is performing Frequency Regulation. In the same manner that a hybrid car battery recycles energy that would otherwise be lost to braking, the GBS smoothes out the starts and stops of the power grid traffic jam by using its batteries as a buffer.

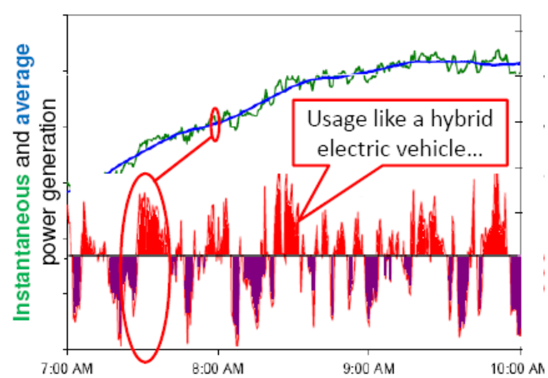

Figure 4
Conceptual Illustration, Varying Cyclic Output for Frequency Regulation

Figure 5 (Loutan, 2007) below is another conceptual illustration of Frequency Regulation for one of the deregulated markets in the U.S., the California Independent System Operator (CAISO).

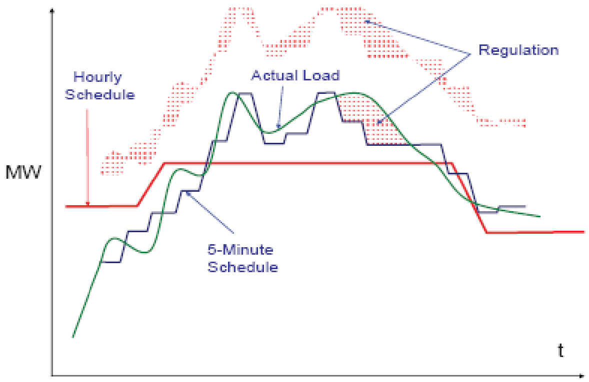

Figure 5
Illustration of CAISO Frequency Regulation

The following CAISO description of Regulation is informative for its clear identification that sufficient regulation resources are needed to meet reliability standards:

> "The CAISO shall maintain sufficient resources immediately responsive to AGC in order to provide sufficient Regulation service to allow the CAISO Balancing Authority Area to meet NERC[2] and WECC[3] reliability standards, including any requirements of the NRC[4] by continuously balancing Generation to meet deviations between actual and scheduled Demand and to maintain Interchange Schedules."[5] (CAISO, 2010)

The ability to dynamically and continuously balance resources and loads is a critical requirement for maintaining stable AC frequency of a microgrid. The relatively small resource pool of a microgrid, versus wide-area networked grids, will likely require relatively higher operational flexibility and a higher proportion of frequency responsive resources.

Extending Our Capabilities, DoE Funded Community Energy Storage Demonstration

In 2009, the U.S. Department of Energy (DoE) selected Detroit Edison (DTE) and A123 to implement and demonstrate a fleet of Community Energy Storage Systems (CES) under the DoE's Smart Grid Demonstration Grants program. The intent is to use proven underlying battery storage and inverter technology in grid storage applications that are not yet common practice nor fully commercialized.

For this project, A123 is extending both our modularity (capacity) and functionality in dimensions that are directly relevant to microgrid applications.

Each individual A123 CES unit will contain a 25 kW battery system with 2 hour duration (50 kWh) capacity. Twenty individual units will be connected in parallel to DTE distribution transformers, all located on the same circuit. The connection voltage is 120/240 V, single phase. Figure 6 below is a conceptual illustration of the unit, configured with the inverter pad mounted and the associated battery placed in a sub-surface box below the inverter.

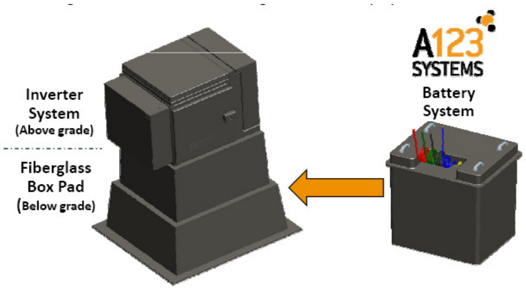

Figure 6
Conceptual Illustration, Single CES Unit

Table 1 below contains the preliminary specification for A123 CES units.

	475 Vdc 50 kWh CES Battery Pack			
	Charge		***Discharge***	
Duration	cont	10 sec	cont	10 sec
Test Pack Power (kW)	13.2	26.3	26.3	79.0
Pack Vmax	542	544	540	540
Pack Vnom	482	484	476	468
Pack Vmin	405	405	401	393
Pack Capacity (AH)	117.6			
Pack Energy (kWHr)	54.6	54.2	54.2	53.4
Total Cell Weight (lbs)	950			
Est Pack Weight (lbs)	1,250			
Pack Dimensions (in)	30 x 33 x 35			
Pack Volume (ft^3)	20.1			

Table 1
Preliminary Specifications, CES Unit

The CES demonstration project will include the CES units operating both individually and as an aggregated fleet under controlled and monitored conditions for a 2 year period beginning in 2012. Several functionalities will be implemented, with performance measured and reported, including,

1) Frequency Regulation: follow disptach AGC (generator control) signal from the MISO (area grid operator)

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[2] North American Electric Reliability Corporation
[3] Western Electricity Coordination Council
[4] Nuclear Regulatory Commission
[5] CAISO, P.18

2) VAR Support: power factor management

3) Voltage Support: meet utility voltgae schedule

4) PV output shifting: store and shift PV output to better coincide with load peak

5) PV output leveling: continuous PV output ramp-rate management

6) Distribution circuit peak shaving: grid operator dispatched or pre-scheduled storage discharge for grid support

7) ***Islanding***: Control schema development for intentional islanding

Islanding Capability and Microgrids

Active islanding of storage to maintain service to load in the event of electrical grid outages will likely provide both direct reliability improvements and indirect avoided-cost improvements. Islanding allows utilities to directly improve customer reliability by allowing continuation of service in the case of loss of grid service. All load downstream of the 'islanded' CES can be supported up to the rating of the unit. To quantify the reliability improvement, load recovered less than 5 minutes after loss can be logged as a "momentary" versus "sustained" outage as measured with SAIDI/SAIFI and CAIDI/CAIFI[6] statistics. Indirectly, active islanding may allow the utility to defer upstream transmission or distribution upgrades. The CES can maintain constant reliability metrics as perceived by the end user even if the power quality delivered to the CES decreases.

The specific U.S. technical standards of performance during islanded performance have not been set, but there are several standards that will provide guidelines, including the ANSI C84 standard for voltage and NERC guidelines related to frequency deviation during normal and emergency conditions. Table 2 below is an example tabular illustration of Southern California's specific off-nominal frequency deviation ride through requirements for wholesale generators[7] (Southern California Edison, 2009).

[6] SAIDI = Systems Average Interruption Duration Index, SAIFI = System Average Interruption Frequency Index, CAIDI/CAIFI are Customer indexes.

[7] Southern California Edison, p. 54

Under Frequency Limit	Over Frequency Limit	Minimum Time
> 59.4 Hz	60.0 to < 60.6 Hz	continuous operating range
≤ 59.4 Hz	≥ 60.6 Hz	3 minutes
≤ 58.4 Hz	≥ 61.6 Hz	30 seconds
≤ 57.8 Hz	N/A	7.5 seconds
≤ 57.3 Hz	N/A	45 cycles
≤ 57.0 Hz	> 61.7 Hz	instantaneous trip

Table 2
SCE's Off-Nominal Frequency Deviation Limits

Additional microgrid-relevant benefits to be demonstrated with this CES project include voltage support in conjunction with PV output management. For example, under sunny skies (high PV output) and light load conditions, power flow on a feeder could reverse and cause over-voltage conditions.[8] (Ueda, 2007) A CES device would not only help keep the neighborhood voltage within specifications, but the battery could also increase the overall efficiency of the system. The excess PV energy would be stored locally in a battery system with >90% round trip efficiency, rather than taking multiple trips through a T&D system with associated typical losses of 7%-13% each way.

Evolving U.S. Interconnection Standards; On the Critical Path for Microgrid Success

The tension and potential conflict between U.S. standards for interconnection of distributed resources and the needed operational capabilities required to implement a microgrid have been recognized and U.S. standards are evolving to support the emerging operational scenario of intentional islands or microgrids.

IEEE 1547 (IEEE, 2003) is the U.S. national standard for the interconnection of distributed resources (10 MW and less) to electric power grids. It contains two core requirements for connecting distributed resources to electric power systems:

1) 1547 compliant distributed resources must have anti-islanding controls to assure disconnection in the event the upstream grid is de-energized or exceeds defined voltage or frequency deviation limits

2) 1547 compliant distributed resources should not actively regulate upstream grid voltages

If distributed resources, including distributed storage, are to support an intentional island, they must be able to withstand and operate through momentary disruptions and deviations in frequency and voltage. Furthermore, resources with VAR capacity must be allowed to

[8] Ueda, p. 1

help regulate the island's distribution voltage. These operational and planning needs for implementation of intentional islands and others (like accounting for reduced Short Circuit Duty once islanded from a bulk electrical grid) are identified and addressed in IEEE 1547.4.

IEEE 1547.4 is currently a draft standard, at the balloting stage. Approval of this guideline may take place in 2011.

Additionally, as Figure 7 below shows, there is a conflict between IEEE anti-islanding limits (the point at which a resource disconnects), and NERC and ERCOT[9] ride through limits (the point through which a unit should continue operation) for generators[10]. (Behnke, 2010)

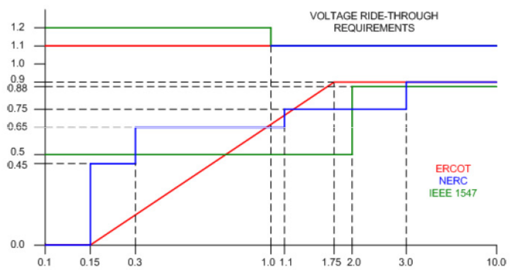

Figure 7
Illustration of Potential Conflict, Ride Through versus Anti Islanding Requirements

These illustrations of potential conflicts between technical standards are intended to inform the reader of the general need across the power industry to evaluate and impart change and enhancement of technical standards to accommodate new technologies and operating practices. Significant work is underway across the power industry to address these and many more technical standards issues that need improvement, if the full promise of Smart Grid enabled operational scenarios, including microgrids, are to be fully incorporated into industry practice.

CONCLUSION

Advanced grid storage systems, including those built by A123, are in service today providing Ancillary Services including Frequency Regulation and Spinning Reserves in open deregulated electricity markets in the U.S. and internationally.

Leveraging commercially proven product components and system level platforms, grid storage systems are adding functionalities that will extend grid resiliency and performance flexibility for substantial system, consumer and societal benefits.

Combining advanced technologies with advanced operating concepts, including microgrids, will support the goal of increasing the amount of clean renewable sourced energy serving end-user electrical energy requirements, while coincidentally preserving reliability and service-security of power grids.

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[9] Electric Reliability Council of Texas
[10] Behnke, p.12