Grid Stability Battery Systems for Renewable Energy Success

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Abstract -- A123 Systems (A123) has deployed over 20 MW's of Nanophosphate™ battery-based systems that are currently providing Ancillary Services in wholesale electric markets. Ancillary Services include Frequency Regulation and Spinning Reserves. This paper outlines A123's early ground breaking grid battery systems. It describes their characteristics and the applications that these energy storage systems are used for today. The paper then discusses how these characteristics and capabilities implemented in A123's current multi-MW scale battery systems can be extended and applied to support increased delivery of clean renewable energy while maintaining reliable and secure grid performance.

***Index Terms*—Advanced batteries, Ancillary services, Energy storage, Frequency regulation, Renewable energy, Renewable portfolio standards, Wind integration**

INTRODUCTION

Since 2008, A123 Systems has deployed over 20 MW's of advanced battery based grid connected energy storage systems. These systems use A123's proprietary Nanophosphate™ Li-ion battery chemistry. Characteristics of this battery chemistry allow creation of battery-based systems capable of dynamic exchange of real power with the connected grid, and thus expand the range of applications and values beyond conventional 'catch and release' temporal shifting of energy, as already done successfully at significant scale today with pumped hydro storage. The enhanced characteristics of advanced-battery based grid systems that allow creation of new expanded functionality include very high efficiency, very high cycle life, and scalability. Today, grid applications leveraging these advanced battery characteristics include Frequency Regulation. The same characteristics that allow for use of batteries at multi-MW scale for Frequency Regulation can also be applied to an emerging grid challenge – integration of intermittent renewable generation. Study of one major U.S. market has identified an indirect opportunity for storage to support integration of more renewable energy, i.e. supporting more renewables by meeting the electric system's expected increase in required Frequency Regulation capacity as the proportion of intermittent renewable resources versus traditional resources increases. A123's own grid simulation studies show that there are additional grid-supportive benefits relevant to renewable integration, specifically, increased system stability through use of large scale multi-MW dynamically-responsive energy storage systems.

I. A123's SMART GRID STABILIZATION SYSTEM

Since 2008, A123 has deployed over 20 MW of advanced battery systems. The systems in commercial operation today are owned and operated by our developer partner AES Storage. Recent deployed projects are comprised of multi-unit arrays of A123's Smart Grid Stabilization System (SGSS). Fig. 1 shows a portion of a 12 MW array of A123's SGSS units that went into commercial service in 2009.

Fig. 1, photo of multiple SGSS units operating in a 12 MW grid storage system

Fig. 2 is an artist rendering of a single SGSS unit.

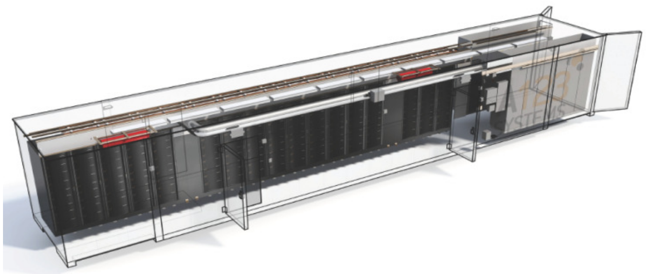

Fig.2, Artist rendering of an A123 SGSS Unit

The basic characteristics of each SGSS unit 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.

A. Ancillary Service

Our grid systems that have been deployed to-date are used for Frequency Regulation and Spinning Reserves. In deregulated U.S. wholesale markets these are defined Ancillary Services, and are procured through bid-based market mechanisms. Ancillary Services are defined in the FERC Open Access Transmission Tariff Pro-Forma Tariff [1]. In simplified terms, Spinning Reserves is a form of back-up where a system is synchronized to the grid, but doesn't 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 (the market-cleared bid capacity) 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 nominal (60Hz in the U.S.). Since electrical grids continuously oscillate bi-directionally 'plus and minus' around the nominal system frequency under normal conditions, 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, our SGSS can be implemented with a power-to-energy ratio of 4:1 to perform this service with an efficient amount of battery capacity.

Fig. 3 is a conceptual simplified diagram of moment-to-moment varying power output required when a grid resource is performing Frequency Regulation. This graphic points out the similarity between the varying output level for Frequency Regulation and a hybrid electric vehicle.

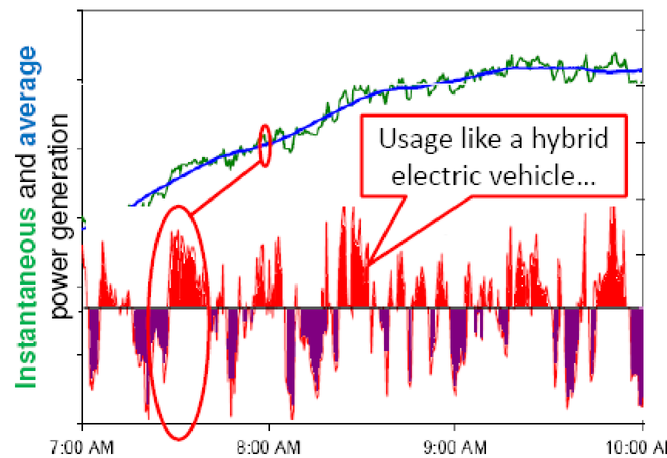

Fig. 3, Conceptual illustration of varying power output for Frequency Regulation cycling around an average plant power output value

Fig. 4 is another conceptual illustration of (Frequency) Regulation for one of the deregulated markets in the U.S., the California Independent System Operator (CAISO).

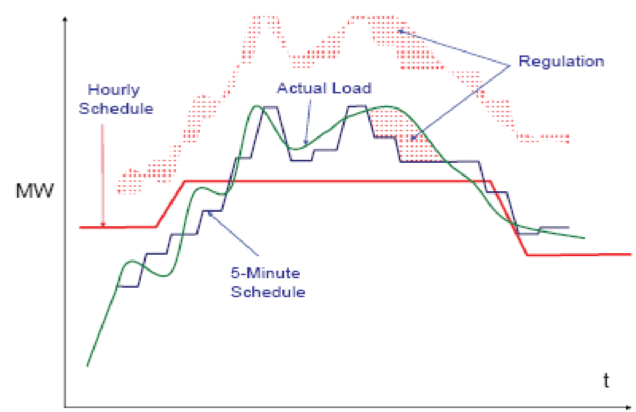

Fig. 4, CAISO's Regulation Requirement Illustration[1]

The following CAISO description of Regulation is informative for it's 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 by continuously balancing Generation to meet deviations between actual and

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[1] [3], p.79
[2] North American Electric Reliability Corporation
[3] Western Electricity Coordination Council

scheduled Demand and to maintain Interchange Schedules."[4]

II. Applying Storage for Renewable Success

For this paper's discussion, "success" is increasing contribution of renewable energy to the overall mix of supplied electrical energy, while maintaining adequate grid performance. Two scenarios are presented below to illustrate the potential for SGSS, or any other storage system with comparable performance characteristics, to support renewable success:

1) Storage providing Frequency Regulation capacity to meet increased demand due to addition of wind generation
2) Storage with dynamic response improving an electrical system's post-outage frequency recovery

A. Wind, Storage, Cleaner Frequency Regulation

California has a 20% Renewable Portfolio Standard (RPS) requirement and a 33% RPS goal. [2] RPS can be simplistically described as the ratio of electrical energy provided by qualifying renewable resources versus total delivered electrical energy for end-use load.

To meet California's RPS, the largest additional contribution of renewable energy will come from added wind generation capacity. Table 1 presents the additional added MW's of various renewable resources assumed in the California ISO's (CAISO) study of 20% RPS impacts. [3]

TABLE I
Added Renewable Resource Capacity
Modeled for CAISO 20% RPS Study[5]

Renewable Resource	MW
Wind	5,035
Geothermal	1.004
Concentrating Solar Power	946
Residential Solar	533
Biomass	221

While this referenced study and report by the CAISO cover numerous operational aspects of integrating a 20% renewable energy, one quantified impact is their estimation of the need for up to 730 MW[6] of additional Regulation capacity due to the modeled grid performance impacts of adding renewable resources to meet California's 20% RPS goal.

This points to one way storage can support successful addition of more wind generation. To the extent added wind generation does increase the amount of needed Regulation capacity to maintain frequency within acceptable limits, adding storage that provides this Regulation will help support the integration of more clean wind energy.

Lower emissions will be an added benefit of using storage for provision of additional Regulation capacity, versus using fossil-fired generation. Prior analysis by KEMA estimated emission savings by using storage versus fossil fired sources for Regulation in the CAISO market.[4] The results of that analysis showed a 70% reduction in CO2 emission for a modeled scenario using 20MW flywheel versus 20 MW natural gas fired combustion turbine[7].

B. Wind, Storage, Improving Dynamic Stability

No serious transient stability or post-transient stability problems were identified in the referenced CAISO 20% RPS study report. But, the referenced report also noted, "Spain has recognized the potential problem of large amounts of wind integration in regard to stability conditions under system fault."[8]

Dynamic stability simulations that A123 performed earlier in 2008 to evaluate storage's capacity to support very high wind penetration in California [5] is consistent with the CAISO report citations above. A123's own dynamic simulations of high wind penetration scenario in California did not identify any stability criteria violations, but there were results for fault/outage simulation cases for which adding storage capacity with frequency droop response significantly improved the modeled system's frequency response to an outage. When comparing "with" versus "without" storage scenarios, the "with" dynamically controlled (frequency droop control) storage scenarios had superior frequency recovery as illustrated in the graphics in Fig. 5a and Fig 5b, below.

[4] "Blacklines for Non-Generation Resources, Fourth Replacement CAISO Tariff", Section 8.2.3.1 Regulation Service, CAISO, P.18, May 18, 2010

[5] [3], p.16

[6] [3], p.82

[7] [4], p.6

[8] [3], p.108

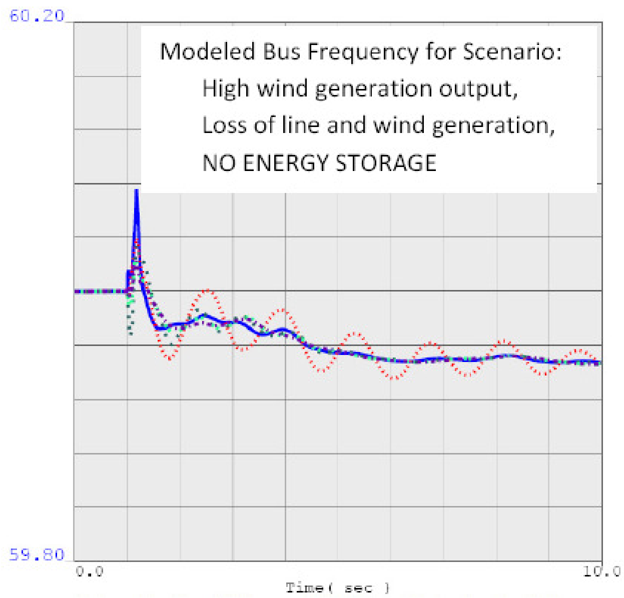

Fig. 5a. Declining bus frequencies in a dynamic simulation run for a high-wind scenario, without storage added to the modeled grid

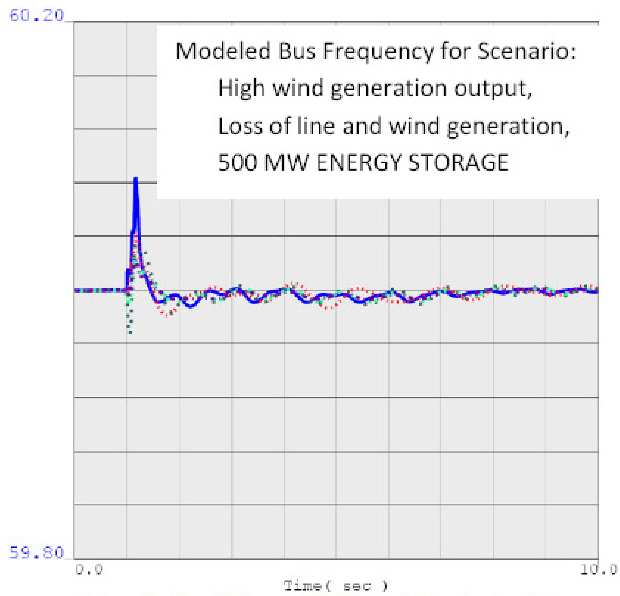

Fig. 5b. Damped and stable bus frequencies in a dynamic simulation run for the same high-wind scenario, but with storage added to the modeled grid

Improving post-outage system frequency recovery absent reliability criteria violation won't justify the deployment of storage. But if storage is deployed for any other reason, like F/R market participation, the added frequency responsive storage will support the integration of relatively more intermittent renewable resources into the shared electrical system.

III. Conclusion

Renewable resources capacity, and in particular wind generation capacity, is expanding significantly and will help achieve RPS targets in California, and in other U.S. States. At the same time, advances in the characteristics, functionalities, and scale of grid storage is progressing as evidenced by A123's and others' commercially deployed multi-MW storage systems that are being used to sell Frequency Regulation. These advances in energy storage technology's characteristics and resulting functional capabilities can be applied to improve the grid's ability to accommodate more renewable energy, above and beyond using energy storage to simply change the timing of when energy produced by a renewable resource is delivered to load. The author hopes to further develop these grid-oriented energy storage application concepts, including dynamic damping enabled through synchrophaser-aided energy storage control schemes, and more rigorously test these concepts' potential technical value and relevance through additional simulation and analysis.

References

[1] FERC Order 888-A "Promoting Wholesale Competition Through Open Access Non-discriminatory Transmission Services by Public Utilities; Recovery of Stranded Costs by Public Utilities and Transmitting Utilities", Appendix B Pro Forma Tariff, http://www.ferc.gov/legal/maj-ord-reg/land-docs/rm95-8p4-000.txt

[2] CA Executive OrderS-14-08, Office of the Governor, Nov. 17, 2008

[3] C. Loutan and D. Hawkins Principal Investigators, "Integration of Renewable Resources, Transmission and operating issues and recommendations for integrating renewable resources on the California ISO-controlled grid", CAISO, Nov. 2007

[4] R. Fioravanti and J. Enslin Principal Contributors, "Emissions Comparison for a 20 MW Flywheel-based Frequency Regulation Power Plant", Beacon Power Corporation KEMA Project Final Report, Jan. 8, 2007

[5] S. Hamilton, "Batteries are Key to Wind Integration", T&D World, December 2008