

ALTI-ESS an Advanced Technology Power Plant for Grid Stabilization Applications

D. K. Nichols, *Member, IEEE*, and M. Brunell

Abstract-- This paper presents a power plant that is optimized for electric power system (EPS) stabilization applications. In this paper, we review the use of electricity storage as a means to improve EPS performance, differentiating between energy and power applications. One power application, the use of fast responding electricity storage to provide ancillary services is explored in detail. The use of fast responding electricity storage for frequency regulation provides better frequency control and reduced regulation requirement, resulting in improved EPS performance and energy efficiency, and reduced carbon emissions. The design basis of a 10 MW ALTI-ESS is presented along with results from a two year frequency regulation project. Interconnection studies completed for Unidad de Transacciones (UT) are presented in a companion paper titled “ALTI-ESS: El Salvador Interconnection Studies”.

Index Terms—automatic generation control, batteries, bidirectional power flow, converters, energy efficiency, electricity storage, environmental factors, power generation dispatch, power system control, power system reliability, frequency regulation, lithium ion batteries.

I. INTRODUCTION

The ALTI-ESS is an Advanced Technology (electricity storage system) Power Plant for Grid Stabilization Applications. This paper will present the technology, design basis, electricity storage applications, and current application status.

Worldwide, efforts are underway to transform the Electrical Power System to improve asset utilization, asset life-cycle management, grid operation and performance, generation capacity, energy efficiency, environmental impact, and better meet customer needs. Electricity storage, advanced communication methods, and power electronics are enabling technologies for transforming the electric power industry. The use of electricity storage for frequency regulation purpose is an example of the evolving grid transformation. In the United States, those efforts must be consistent with The Federal Energy Regulatory Commission (FERC) regulations. FERC is an independent agency that regulates the interstate transmission of electricity, natural gas, and oil.

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At all times, it is necessary to balance the generation of electricity with its usage. When that equilibrium is out of balance, system generators speed up or slow down and in severe cases the EPS may go unstable.

The instantaneous balance between generation and load within an interconnected electric power system is directly reflected in the *frequency* of the interconnection. Reliable operation of a power system depends on maintaining frequency within predetermined boundaries above and below a scheduled value, which, in North America, is normally 60 Hertz (Hz). Failure to maintain frequency within these boundaries can disrupt the operation of customers' equipment, initiate disconnection of power plant equipment (to prevent them from being damaged), and lead to wide-spread blackouts. [1]

Historically, Power System operators manage or control frequency mainly through adjustments to the output of generators. Recent electricity storage projects have demonstrated that electricity storage provides better frequency control at lower cost than traditional generation, consistent with grid transformation goals.

II. ALTI-ESS DESIGN BASIS

ALTI-ESS is an advanced technology power plant designed to address Grid Stability. Based on Altairnano's Lithium Titanate battery technology, the system can provide fast regulation service. The ALTI_ ESS:

- Operates in all four quadrants to provide real and reactive power
- Improves grid stability by injecting or absorbing real power
- Provides reactive power to the grid, thus providing voltage support.
- Relieves the need for generators to provide reactive power
- Dampens grid oscillation or renewable smoothing

A 1MW ALTI-ESS Power Plant consists of multiple subsystems, including;

A. Power Module (PM)

The module consists of 1 x 1.0MW battery stack, Battery Management System (BMS) and auxiliary equipment in a 53' container.

B. Power Control System Module (PCS)

The module consists of the Power Electronics (AC/DC System) and the Control and Communication systems (PLC, SCADA, and Data Service Unit). It is the gateway to the grid

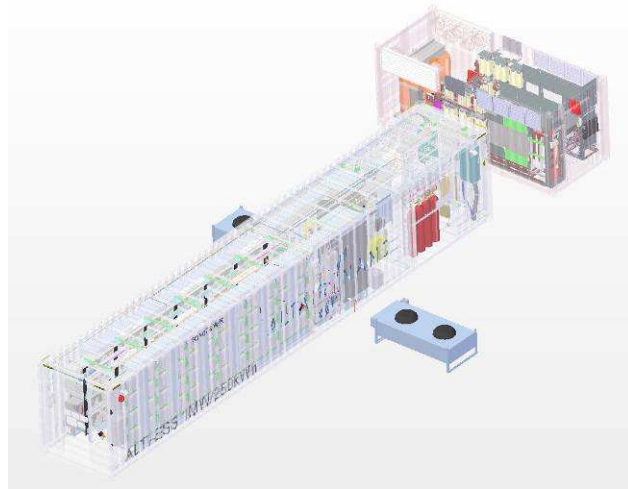


Fig. 1. A 1 MW ALTI-ESS power plant

C. Balance of Plant (BOP)

Balance of equipment necessary to make the ALTI-ESS an integral unit (transformers, module interconnection, utility interconnection) The balance of plant is site specific

D. Grid Interconnection

Technical requirements for interconnection at Distribution voltages are well defined by IEEE 1547-2003-Standard for Interconnecting Distributed Resources with Electric Power Systems. General Requirements at the point of common coupling include requirements for:

- Voltage Regulation
- Integration with Area EPS Grounding
- Synchronization
- Response to Area EPS Abnormal Conditions
- Voltage Disturbances
- Frequency Disturbances
- Disconnection for Faults
- Power Quality
- Limitation of DC Injection
- Limitation of Voltage Flicker
- Anti-Islanding
- Inadvertent Energizing of the Area EPS
- Monitoring
- Isolation Device
- Loss of Synchronism
- Feeder Reclosing Coordination
- Harmonics
- Surge Capability

For Transmission connected systems, it is necessary to modify the under and overvoltage settings to provide low voltage ride through capability. In addition, some owner/operators of the system may want to change the under voltage trip settings to enhance Grid stability. The ALTI-ESS is IEEE 1547

compliant and provides provision to customize voltage and frequency trip settings

III. ELECTRICITY STORAGE

Electricity storage interconnected to the power system through power electronics enables more efficient balancing of power supply and demand. Power electronics allow precise and rapid switching of power and voltage support.

Megawatt-scale electricity storage systems can significantly reduce transmission system congestion, help manage peak loads, make renewable electricity sources more dispatchable and increase the reliability of the overall electric grid. Electricity storage provides solutions to many Energy Delivery operational problems and can be used to defer upgrades to existing infrastructure. Storage can also be more efficient than generation in providing certain ancillary services such as frequency regulation and spinning reserves, providing instant response with very little energy consumption or emissions of greenhouse gases.

Electricity storage provides opportunity to make the EPS more:

- Reliable
- Secure
- Economic
- Efficient
- Environmentally friendly
- Safe

Electricity storage power, energy, duty cycle, and functionality requirements are dependent on application and grid domain (e.g., transmission, distribution, consumer, etc.). [2] High value applications include;

Power Quality & Reliability

- Ancillary services (e.g. frequency, voltage, power quality support) such as spinning reserves.
- Startup smoothing
- Black start, islanding
- Grid support
- Area frequency control.
- First swing stability and damping
- Angular Stability
- Backup power
- Bridge to backup power
- Critical Mission

Renewable Support

- Variable generation shaping
- Ramp rate control
- Mitigate intermittencies
- Electricity storage for stand-alone power systems (solar/wind)
- Shifting time of peak output to match system demand (solar/wind)

These applications can be subdivided into two main categories dependent on discharge time.

A. Energy Applications

These applications provide electricity for long durations, typically 2-8 hours

1) Applications

- Peak Shifting
- Incremental Energy Value
- Renewable time shifting
- Arbitrage T&D Asset Deferral

2) Attributes

- Low Charge/Discharge Rates
- Long Duration (2-8 hrs)
- 1-2 cycles per day
- Less frequent use

B. Power Applications

These applications provide electricity for short duration, typically less than 1 hour.

1) High Power Applications:

- Area Regulation
- Reserve
- Renewable Ramping, Enabling Access to Full Energy Value
- Primary frequency control
- Secondary frequency control
- System inertia
- Back Up Power

2) Attributes

- Very high Charge/Discharge Rates
- Short Duration (<1hr)
- Many cycles (100s per day)
- Continuous use

IV. FREQUENCY REGULATION

A. Frequency control basics

1) Frequency regulation

Frequency regulation is an ancillary service that corrects for short-term changes in electricity. At **all** times, demand and generation must balance. When demand exceeds generation, the power system generators slow down and frequency decreases. When generation exceeds load, the system generators speed up, increasing frequency. Fig. 2 illustrates a typical regulation signal. Electricity storage is well suited to provide this service

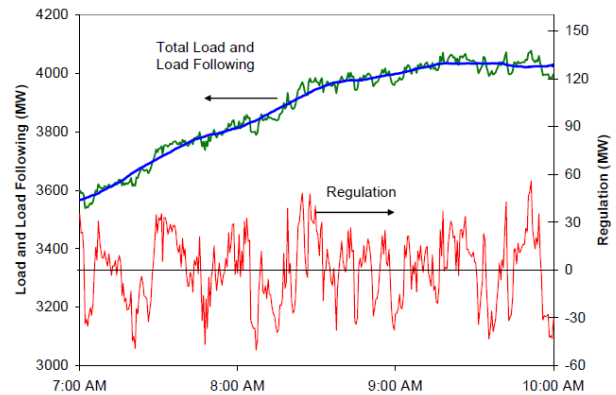


Fig. 2. Regulation is near zero-energy service compensation for minute-to-minute fluctuations in total system load and uncontrolled generation [3].

2) Frequency response

When the power system experiences a loss-of-generation event, system load immediately exceeds generation, and frequency begins to decline, rapidly. Through governor response, the remaining connected generators provide immediate increase in power to retard frequency decline and stabilize system frequency. This automatic and autonomous control occurs within the first 30 seconds of an event is called Primary Frequency Control. Secondary Frequency Control actions, because they are externally directed, are too slow to contribute to the arrest and stabilization of frequency in the short time available. The inter-relationship between these frequency control functions is illustrated in Fig. 3. [1] A properly designed electricity storage system can be utilized to provide inertia and Primary Frequency control to mitigate frequency decline and participate in Secondary Frequency control. This functionality has not yet been demonstrated.

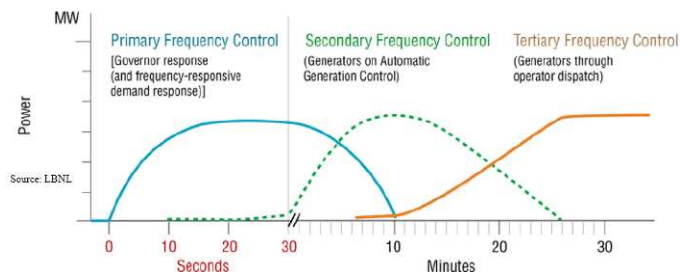


Fig. 3. Types of frequency control by timeframe

B. Fast Responding Frequency Regulation

Electricity storage systems provide near instantaneous response to the regulation control signal, providing more energy to the power system than other Regulation resources. This energy contribution is illustrated in Fig. 4, comparing the fast response of electricity storage against traditional energy sources.

The effectiveness of fast responding electricity storage (FRES) is further illustrated in Fig. 5, comparing a slow ramping generator to an advanced electricity storage system

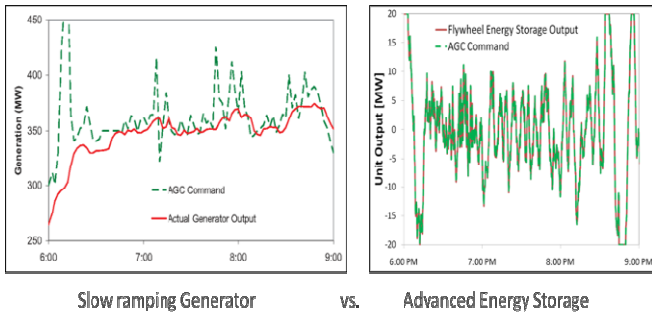


Fig. 4. Comparison of response rates.

Studies have shown that fast responding electricity storage works much better for frequency regulation. A Pacific Northwest National Laboratory report [4] concluded that fast regulation resources are more effective with less resources required than traditional generation. That report found that:

- Fast response resources can reduce CAISO’s regulation procurement by up to 40%
- Fast regulation is as much as 17 times more effective than some ramp limited technologies

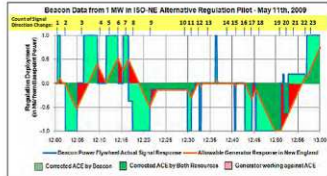
Comparing ramp rates of various generation sources clearly shows the advantage of fast responding electricity storage to provide regulation service. By correcting Area Control Error (ACE) quickly, less regulation is needed. Regulation procurement is reduced because

1. fast responding electricity storage resources reach their dispatch target more quickly, and in turn provide more power and energy in real-time
2. fast responding electricity storage is ready to be re-dispatched more often
3. Slower ramping resources sometimes provide regulation in a direction that is counter to the regulation signal, and add to ACE.

The effectiveness of fast responding electricity storage is further illustrated in Fig. 5 from Electricity Storage Association (ESA) response to Federal Energy Regulatory Commission (FERC) Notice of Proposed Rule (NOPR) [5]. A fast responding resource delivers significantly more energy to correct Area Control Error.

Methodology for determining the comparative capacity value of each resource

- Compare the ACE Correction provided by each resource over the average time period the ACE changes direction
- Use this ratio to determine the capacity
 - In this example, if a transmission customer were to self-supply regulation with the fast resource, it should be allowed to satisfy its Regulation obligation with 0.26 times or about 1/4 the capacity
- Ensures just and reasonable rates by encouraging self-supply from the most efficient resources available



Resource	Capacity (MW)	Ramp Rate (MW/min)	ACE Correction per hour (MWh)	ACE Correction per 2.6 mins (60 mins/23)
Fast-ramping Storage resource	1	15	0.48	0.043
Slower-Ramping Generator	1	0.2	0.11	0.011
Ratio (Fast : Slow)	1x	75x	4.4x	3.8x

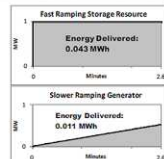


Fig. 5. Illustrates the effectiveness of fast regulation

Comparing the ramp rates of various generators illustrates the ramp rate advantage of electricity storage compared to traditional generation.

Table 1. Generator ramp rates

Generation Type	Ramp Rate/Min %	Typical Size MW	Ramp Rate/Min MW	Installed MW to Provide 500MW of Ramping in 10 Seconds
Nuclear	NA	1,000	-	-
Coal	2.50%	500	12.5	120,000
Combined Cycle (CCGT)	5.00%	500	25.0	60,000
Gas Fired Steam	3%	200	6.0	100,000
Gas Turbine	20%	100	20.0	15,000
Energy Storage	3000%+	20	6,000	500

C. Adoption of Electricity storage in the United States

United States energy policy has supported the development of electricity storage as a means to improve EPS performance through Department of Energy (DOE) RD&D efforts and policy. EAct 2005 states US policy encourages use of demand response and the elimination of unnecessary barriers to demand response participation in energy, capacity, and ancillary services markets. Electricity storage is considered as a case of demand response, as it can be used to decrease demand.

Federal Energy Regulatory Commission (FERC) Order 890 (Feb 2007) allows non-generating resources to participate in ancillary services along with generation resources. In response, ISOs enacted rule changes to allow non-generating units to participate in Ancillary Service markets.

In February 2011, FERC issued a Notice of Proposed Rule endorsing Pay for Performance (Feb 2011). This NOPR recognizes the value of fast responding devices ISOs incorporating pay for performance concepts in markets. The new rule would incent the use of accurate and fast responding resources.

Currently, the installed or planned fast responding electricity storage fleet is at 124 MW. This fleet is expected to grow with the adoption of the recent FERC order.

Energy Storage projects in ISO/RTO Markets in the United States

ISO/RTO Organized Market Applications				
Technology	Owner/Technology Provider	Operating Capacity	Commercial Operation Date	ISO/RTO
Flywheel	Beacon/Beacon	Up to 3 MW	November 2008	ISO-NE
Battery	AES/A123	8 MW	December 2010	NYISO
Flywheel	Beacon/Beacon	20 MW	January 2011	NYISO
Battery	AES/Altairano	1 MW	May 2009	PJM
Battery	AES/A123	32 MW	2011	PJM
Flywheel	Beacon/Beacon	20 MW	2012	PJM
Battery	AES/A123	2 MW	2008	CAISO
Battery	Prudent Energy	Up to 750kW	Q4 2012	CAISO
Battery	AES/Altairano	1 MW	In Operation	ERCOT
Battery	Xtreme Power	36 MW	Q3 2012	ERCOT
Total		124 MW		

V. PJM DEMONSTRATION

The ALTI-ESS battery system has undergone commercial validation over a two year period at PJM.

A. Who is PJM

- PJM Interconnection is a regional transmission organization (RTO) that coordinates the movement of wholesale electricity in all or parts of Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia and the District of Columbia.
- Acting as a neutral, independent party, PJM operates a competitive wholesale electricity market and manages the high-voltage electricity grid to ensure reliability for more than 54 million people.
- PJM Interconnection coordinates the continuous buying, selling and delivery of wholesale electricity through the Energy Market

B. Results from a Two Year Program

During that two year validation, the system

- Demonstrated reliable operation and interaction with the grid
- Performed over 250,00 small cycles and charged/discharged 3300 MW
- Exceeded 95% availability, generating revenue in line with plans
- Experienced less than 2 % energy capacity degradation with no power degradation
- Is expected to maintain power and energy capacity for over 20 years with no replacement or upgrade.

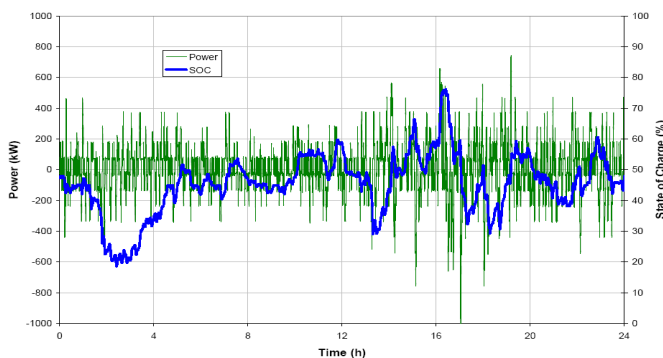


Fig. 6. Typical 24 hour charge/discharge cycle.

Examination of a typical daily cycle, shows that the state of charge of the system maintains a nearly neutral balance state of charge as the battery is charged and discharged to meet regulation requirements.

VI. A PROPOSED 10 MW ALTI-ESS FOR TALNIQUE STATION

A 10 MW ALTI-ESS is proposed for Inversiones Energéticas' (INE) Talnique power station to provide frequency regulation service. A rendering of the proposed plant is shown in Fig. 7.

Proposed for INE :A 10 MW ALTI-ESS Plant Power



Fig. 7. The proposed 10 MW plant.

VII. ALTI-ESS 10 MW GRID INTERCONNECTION STUDY DISCUSSION OUTLINE

To connect the ALTI-ESS to the El Salvador grid, it is necessary to perform an Interconnection Study to asses Grid impacts. That Interconnection Study includes

- Steady State Study
- Short Circuit Study
- Transient Stability Study
- Electro-magnetic Transient (EMT) Study
- ALTI-ESS Modeling

Results of those studies indicate that the ALTI-ESS has no adverse impact of the power system. The report is detailed in a companion paper titled "ALTI-ESS: El Salvador Interconnection Studies".

VIII. OTHER HIGH VALUE POWER APPLICATIONS

Each of the following applications benefit from high powered electricity storage devices that are able to charge and discharge at very high power pulses that would otherwise increase strain on the electrical system or be rejected through resistor banks.

A. Grid Applications

1) Renewables Integration

The intermittency and variability of renewable resources such as wind and solar benefit from fast response high power electricity storage devices. These applications require high power output for short durations such as a few seconds to minutes. The inclusion of the high powered electricity storage device assists in the integration of renewables to support a stable grid.

Applications include:

- Renewables Ramping
- Renewables Firming

2) Microgrid Applications

Microgrids benefit from high powered electricity storage devices as it allows local generation to run efficiently with the storage device handling the moment to moment fluctuations in the local grid. Benefits include voltage support, UPS capability for short durations, frequency regulation, as well as other grid support services.

Applications include:

- Building elevators and lifts
- Support Building microgrids
- Remote village/Island grids

B. Non-Grid applications

1) Industrial and Vehicle Applications

Non-grid applications require high power electricity storage devices that can accept the regenerative power produced in actions such as lowering a load of a crane, lowering of the forks on a forklift, or the breaking from a large vehicle. In each case the application requires both high power discharges as well as high power charge capability.

Applications include:

- Cranes
- Forklifts
- Fast Charge EV Bus

IX. CONCLUSION

A. Fast responding electricity storage:

- Reduces overall regulation requirement
- Provides more effective and tighter control (CPS1 & CPS2)
- Provides asset deferral by reducing the need for new fossil-fuel powered peaking power plants.
- Assists integration of intermittent renewable resources (wind, solar)
- Lowers cost to ratepayers
- Reduces Generator O&M costs by reduced cycling
- Improves generator efficiencies

B. ALTI-ESS Enhances El Salvador's Electrical Power System

- Improves AGC Control Performance Standard
- Provides improved frequency control
- Provides AGC reserve during wet and dry seasons
- Stabilizes real time energy balance
- Reduces greenhouse gas emissions
- Improves generator efficiencies by reduced ramping
 - Traditional units run base load
- Reduces cost of ancillary services and energy
- Reduces O&M because traditional generators cycle less
- Reduces ramp rate requirement on remaining fleet

C. ALTI-ESS Future High Value Applications

- Black start
- Primary frequency response
 - Governor response
 - Generator AGC response
- Photovoltaic smoothing
- Wind firming
- Wind ramp rate control
- Microgrids, electrical islands
- Voltage regulation

X. REFERENCES

- [1] Eto, J., Use of Frequency Response Metrics to Assess the Planning and Operating Requirements for Reliable Integration of Variable Renewable Generation, LBNL -4142E, Dec 2010
- [2] Eyer, J., Corey, G., Energy Storage for the Electricity Grid: Benefits and Market Potential Assessment guide, SAND2010-0815, FEB 2010
- [3] Kirby, B., 2004. Frequency Regulation Basics and Trends, ORNL/TM-2004/291, Oak Ridge National Laboratory, OakRidge, TN, January.
- [4] Makarov, Y.V, Ma, J. Lu, S. Nguyen, T.B. "Assessing the Value of Regulation Resources Based on Their Response Characteristics." Pacific Northwest National Laboratory, PNNL -17632, June2008.
- [5] Electricity Storage Association(ESA) submission in response to FERC Notice of Inquiry pertaining to Third-Party Provision of Ancillary Services; Accounting and financial Reporting for New Electric Storage Technologies, 135 issued June 2011. Docket Nos.RM11-24/AD10-13
- [6] DOE Electricity Advisory Committee, Bottling Electricity: Storage as a Strategic Tool for Managing Variability and Capacity Concerns in the Modern Grid, 2008. [Online]. Available: www.doe.energy.gov/eac
- [7] IEEE Power Energy Mag., Bottling Energy Issue, vol. 7, no. 4, Jul./Aug. 2009.
- [8] KEMA, Benefits of Fast-Response Storage Devices for System Regulation in ISO Markets, June 2008 AES Corporation Rep., 2008.

XI. BIOGRAPHIES



David Nichols (M) was born in Akron, Ohio in the United States of America, on May 17, 1949. He received a BSEE degree from Akron University in 1972. While at Akron University, he focused on power engineering, and control and communications theory.

Currently, David K. Nichols is the Stationary Power Product Manager at Altairano, Inc. Previous to joining Altairano, he was the US Market Development Manager for Rolls Royce Fuel Cell Systems. In that role, he was responsible for grid interconnect and certification issues, as well as developing relationships with electric utilities to understand requirement for utility and utility customer applications. Previous to joining Rolls-Royce, Mr. Nichols held numerous positions with the American Electric Power Service Corporation. He held various managerial positions in AEP's Research and Corporate Technology Development Departments, including managing AEP's Dolan Technology Center in Groveport, Ohio.



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Currently, Michael Brunell is the Applications Engineer as Altairano, Inc. Previous to joining Altairano, he was a Business Development Associate at Ormat Technologies in Recovered Energy Generation. In that position he was responsible for proposal preparation, power purchase agreement reviews, and initial vetting of applications.