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CIGRE US National Committee
2012 Grid of the Future Symposium

Frequency Response from Autonomous Battery Energy Storage

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SUMMARY

Primary frequency control, also known as frequency response or frequency containment reserve, is the rapid change in power output that initially stabilizes frequency after an unexpected outage. While often provided by synchronized generators, new technologies such as energy storage are also able to provide this service. A 12 MW battery energy storage system (BESS) was installed in northern Chile, offloading the primary frequency control obligation of a thermal generator. The system, in operation since 2009, operates autonomously using local control and monitoring. This paper provides an overview of the need, system design choices, and operational results of the BESS.

KEYWORDS

Energy Storage, Primary Frequency Control, Frequency Response

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Background

The Independent Economic Dispatch Center (CDEC) of the Northern Chilean Interconnected Grid (SING) requires generators to reserve 3% to 5% of their capacity for frequency response, or Control Primario de Frecuencia (CPF). [1] If the grid frequency drifts beyond a deadband around 50hz, generators must respond to correct the excursion. The CPF reserve obligation represents a lost opportunity cost. For example, a 277 MW unit with a 4% reserve obligation is limited to 266 MW of generation under normal conditions in order to preserve sufficient CPF headroom. The remaining 11 MW is normally unavailable to produce energy, representing unproductive capacity. In 2009, CDEC-SING approved a rule to allow a Battery Energy Storage System (BESS) to offload the generator CPF reserve obligation. [2]

Design Solution

In 2009, a 12MW, 4MWh BESS was installed in northern Chile in order to offload some of the reserve obligation of a 277MW generation station. The generation station is comprised of two units. Unit 1 (NTO1) has a capacity of 136 MW and unit 2 (NTO2) has a capacity of 141 MW. [3] The planning and design of the BESS was previously discussed in [4], prior to installation. The system consists of eight 1.5MW, 500KWh containerized storage systems, as shown in Figure 1.[2] Each container houses lithium nanophosphate cells arrayed in a modular and hierarchical configuration of packs, trays, racks, and containers, as shown in Figure 2. The containers also house inverters which provide the three phase connection to the low side of a step up transformer.

Figure 1: View of the BESS installation in Northern Chile

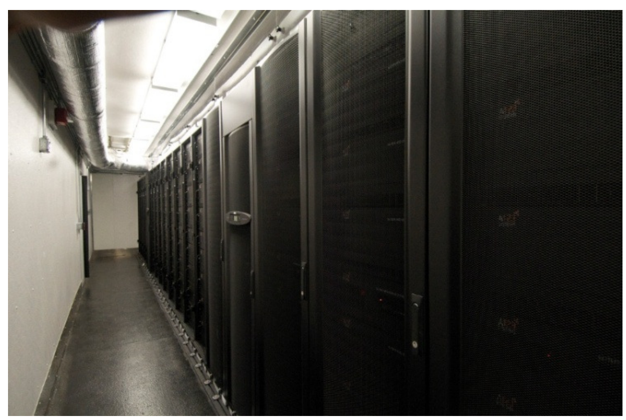

Figure 2: View inside a BESS container

System Design

The BESS continuously monitors the local frequency, which is nominally 50Hz. The CPF performance requirement necessitates logic and intelligence at the end point. The time required to send measurements sent back to a central dispatch system and instructions to the BESS would introduce too much latency to provide CPF. This algorithm uses a threshold of nominal -0.3Hz to initiate a CPF cycle, where all containers are brought to full power in response to the event. Upon recovery above a second threshold, in this case -0.1Hz, the system reverts to its standby mode of operation. The BESS can also respond to over-frequency events using similar thresholds. Figure 3 and Figure 4 illustrate the controller design and interface for the BESS.

[2] While each BESS container is nominally rated at 2MW, the inverter has been derated to 1.5MW for altitude.

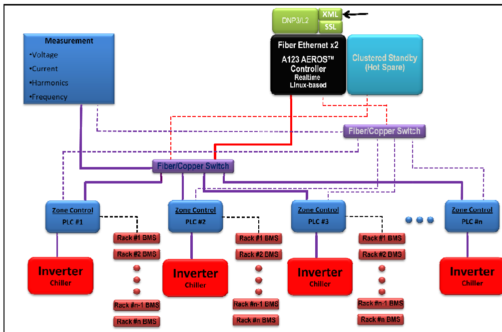

Figure 3: Block diagram of the BESS control system

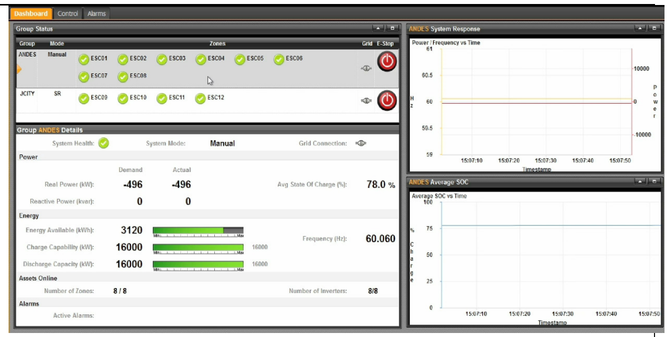

Figure 4: GUI remote monitor for BESS operations

Initial Results

Figure 5 shows the response of the BESS to an under-frequency event. [5] The blue line plots the grid frequency, which drops at time 14:49.30 from 49.91 to 48.81. The ESS quickly provides its full 12MW. The speed of SCADA strip chart sample elongates the time between the start of the event and the response. Actual full power response times can occur as fast as tens of milliseconds, although typical latencies are in the hundreds of milliseconds. Figure 6 illustrates a case where a load was dropped due to a transmission fault. [6] Frequency increased over the upper threshold, and the ESS compensated by pulling power off the grid. In both cases, after frequency returned to the deadband, the BESS then initiated a charge or discharge cycle, as required, to return the state of charge to a predefined set point.

Figure 5: Autonomous response to loss of generation

Figure 6: Autonomous response to loss of load (transmission)

Operational Results

The BESS has enabled the generation station to increase power output and provide more reliable response to frequency deviations. Figure 7 shows the generator steady state output and the observed CPF response in response to approximately 200 contingency events from 2007 to 2012. The graph shows an increase in generator output and greater consistency of frequency response after the BESS was installed in November 2009. Table 1, quantifies the increase of both quantities. Gross generator output increased from approximately 253 MW to 267 MW. The typical CPF response increased from approximately 6 MW to nearly 12 MW.

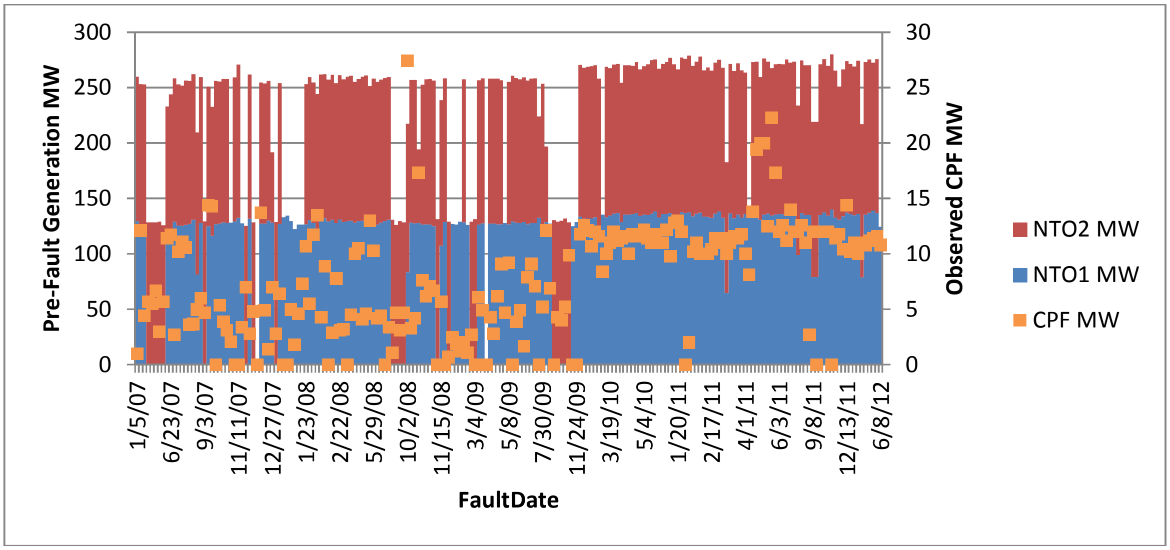

Figure 7: Generator output MW (left-hand axis, red and blue bars) and primary frequency response MW (right-hand axis, orange squares) in response to fault events from 2007-2012.

Table 1: Comparison of generator steady state output and provided CPF, without and with the BESS

	Average Pre-Fault Generator MW	Average Observed CPF MW
Before BESS Installation	253.06	6.22
After BESS Installation	266.83	11.67

Figure 8 and Figure 9 illustrate the steady state output of the individual generator units immediately prior to a fault event requiring CPF deployment. The histograms compare the MW outputs before and after the BESS installation and show that the BESS enables the generator units to operate much closer to their respective maximum capacities. The average output of NTO1 increased from 126.5 MW to 131.5 MW, and NTO2 increased from 126.6MW to 135.3 MW. The generator owner noted that the increase was attributable to both the BESS and "well-managed operations." [3]

Figure 10 shows the frequency response performance of the BESS. As discussed in the System Design section, the BESS uses a +/- 0.3 Hz dead band. The BESS responds to frequency excursions below the dead band with a full raise, while excursions above the dead band receive a full lower.

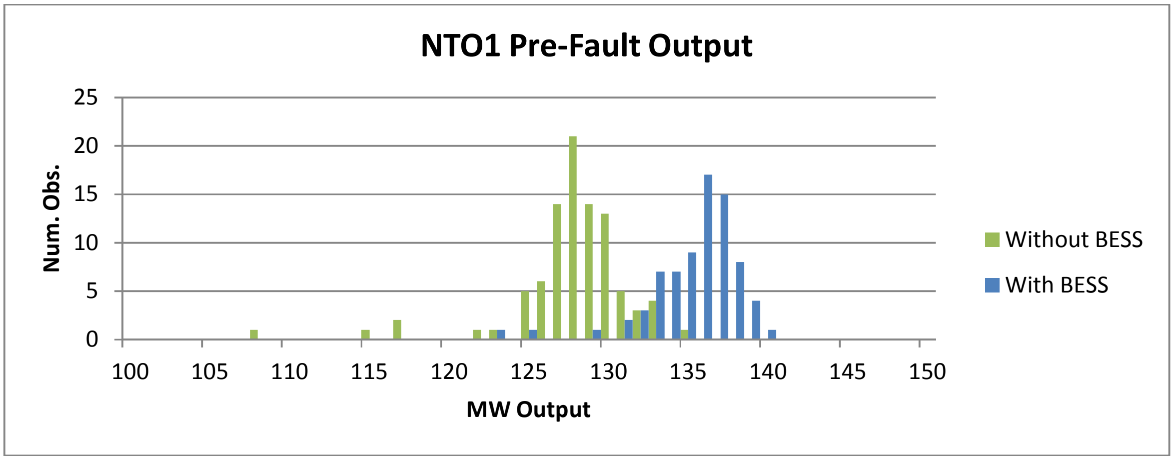

Figure 8: Histogram of the pre-fault steady state output of the 136 MW unit NTO1, demonstrating an increase in output from without the BESS (green) to with the BESS (blue). Points below 100 MW not shown.

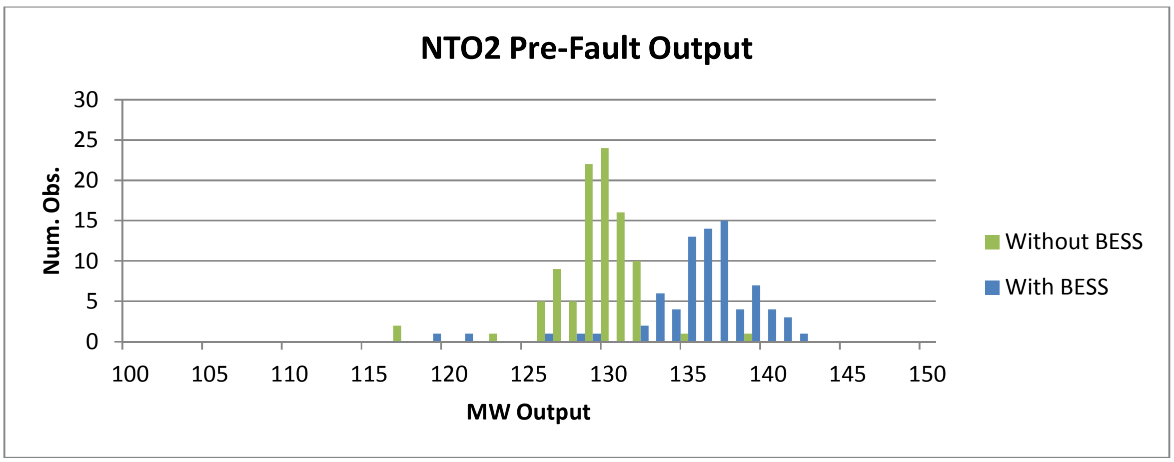

Figure 9: Histogram of the pre-fault steady state output of the 141 MW unit NTO2, demonstrating an increase in output from without the BESS (green) to with the BESS (blue). Points below 100 MW not shown.

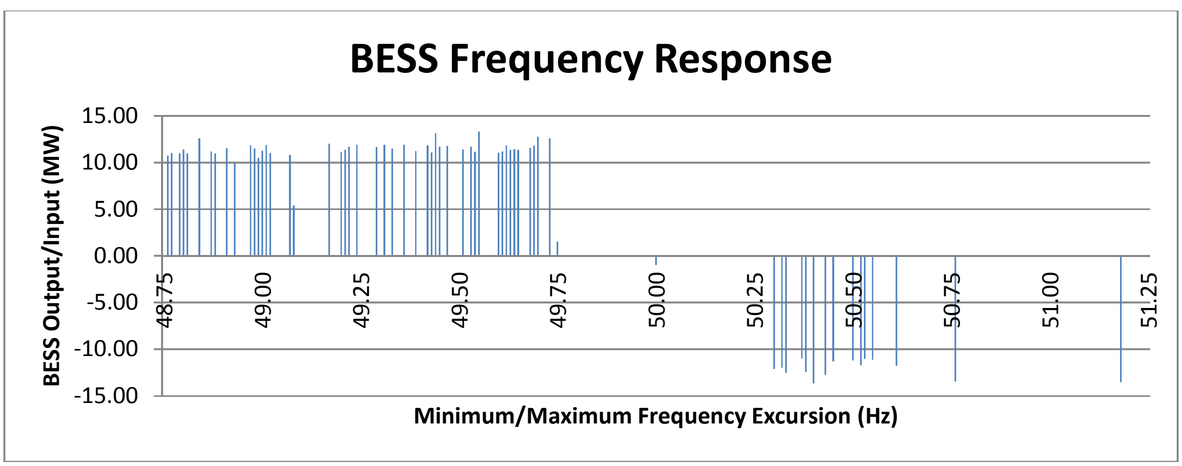

Figure 10: Observed frequency response of the BESS from events in 2010

Figure 11 illustrates the CPF performance of the combined generator and BESS. The pre-BESS system exhibited peaks at 0 MW, 5MW, and 10 MW, since one or both units, each providing about 5 MW of reserves, may have been offline or unavailable for CPF. The post-BESS system has a single peak near 12 MW, representing the nameplate rating of the BESS. The BESS is able to deliver CPF even when the thermal generators are offline, a significant advantage compared to standalone generators. In one case, the BESS delivered 11.2 MW of CPF while unit NTO2 tripped. [7]

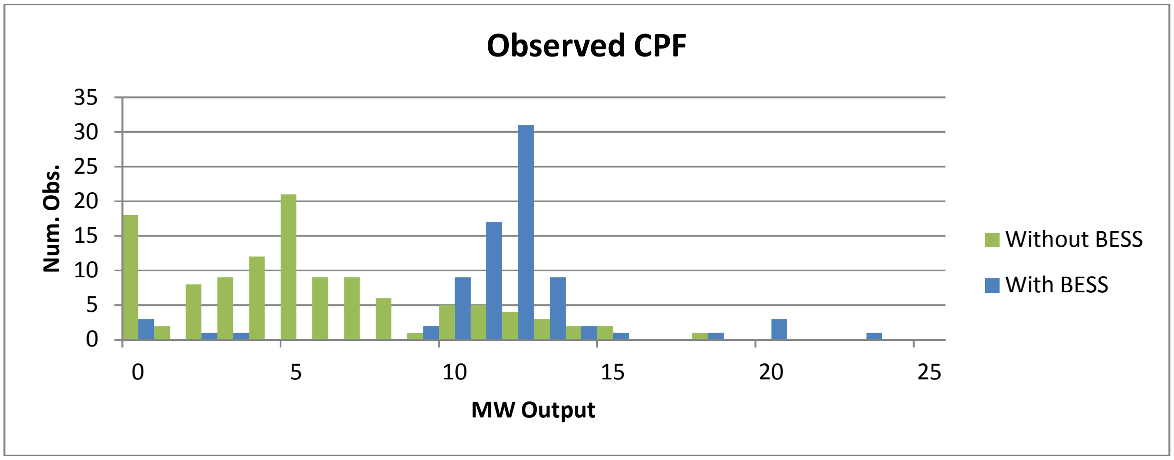

Figure 11: Histogram of primary frequency control (CPF), comparing performance with (blue) and without (green) the BESS.

The instantaneous power delivery of the BESS, based on autonomous intelligence located at the device, allows the generator to free up 4% of capacity that was being held in reserve for CPF. The modular design of the BESS has provided reliable operation and facilitates maintenance procedures, contributing to the extremely reliable performance record.

Future Applications

Due to the excellent performance of the 12MW system, the generator owner has installed an additional 20MW system near a separate 500MW generator, also in SING. The same BESS design will also be useful in other regions where primary frequency control is or will be a requirement. For example, the North American Electric Reliability Corporation has an open ballot for frequency response, the U.S. term closest to primary control. [8] The European Network of Transmission System Operators for Electricity is standardizing reserves terminology and technical specifications, including Frequency Containment Reserve, the proposed harmonized term for primary control. [9]

Conclusion

A 12MW BESS has been installed adjacent to a 277MW generator in northern Chile. The BESS responds to both under-frequency and over-frequency events by charging or discharging, as necessary. The installation has increased the gross output of the generator and demonstrates the commercial feasibility of providing primary frequency control from an energy storage system. Successful operation over several years validates the design choices made to place intelligence at the end point.

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