Energy Storage System Performance Testing

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Abstract
This paper describes the energy storage system data acquisition and control (ESS DAC) system used for testing energy storage systems at the Battery Energy Storage Technology Test and Commercialization Center (BEST T&CC) in Rochester, NY. The system performs functional, performance, and application testing of energy storage systems from 1kW to more than 2MW. This paper contains an overview of the system architecture and the components that comprise the system, practical considerations for testing a wide variety of energy storage technology, as well as a recent test scenario for community energy storage system testing.

Introduction
Energy storage systems (ESSs), and particularly battery energy storage systems, are finding their way into a very wide range of applications for utilities, commercial, industrial, military and residential power. Applications include renewable integration, frequency regulation, critical backup power, peak shaving, load leveling, and more. Some ESSs are designed to power a load over long durations, while others maximize energy, response time, and charge/discharge rates. ESSs range from less than 1kW to several MW in scale. Chemistries range from Li-Ion, NiMH, NaNiCl, NaS, ZnO, Na^+, and $PbSO_4$; and technologies range from standard to flow, metal, and super-capacitors. Practical difficulties with testing such a wide range of energy storage technologies include the wide range of applications, measurements, electrical connectivity, and digital communication protocols. Therefore, an extremely flexible ESS DAC is required.

In New York State, ESSs are being relied upon to minimize investments in new power generation, transmission and distribution infrastructure while the state prepares to reduce nuclear power generation amid increasing overall demand for energy. This has brought rise to the BEST T&CC, an independent test lab operated by DNV GL. The lab's mission is to encourage innovation and development of critical energy storage technology in order to improve reliability and resiliency in electrical grid and transportation applications.

DNV GL partnered with Bloomy to develop a highly flexible ESS DAC system to support a maximally wide range of ESS testing. The ESS DAC system has been used in DNV GL's ESS Performance Test Lab in Chalfont, PA for test, inspection, and certification of ESSs up to 2MW. Currently, the ESS DAC System is deployed at the BEST T&CC for performance testing of smaller scale ESSs up to 240 kW. This paper describes the ESS DAC System architecture, hardware, and software, and presents a CES test scenario.

ESS DAC System Requirements

The ESS DAC system must perform comprehensive ESS characterization as well as application testing in a lab environment, and must also be rugged and transportable for the field. The system is required to perform all of the power grid, system, battery, inverter, load, and ambient measurements summarized in Figure 1. The system must perform high-precision dynamic measurements of both high and low voltages and currents without susceptibility to noise. The system must support multiple communications protocols for monitoring and controlling the ESS via the master controller and battery management system. The system must be designed in a manner to isolate and protect the highly sensitive measurement electronics from high voltages, currents, and electromagnetic interference, while also protecting the operator.

Figure 1. ESS DAC Measurements	
PCC interconnected voltage	Sample battery cell voltage
PCC interconnected voltage frequency	Sample battery cell current
System AC voltage	Sample minimum battery cell temperature
System AC current	Sample maximum battery cell temperature
AC Real power	Battery enclosure ambient temperature
AC Reactive power	Ambient outside temperature
System power factor	PCS (inverter) AC voltage
System current and voltage total harmonic distortion	PCS (inverter) AC current
System current and voltage harmonic relative to 60 Hz component	PCS (inverter) AC frequency
System demand power kW	PCS (inverter) AC temperatures heat sink
System energy kWh	PCS (inverter) AC temperatures cooling media
Battery DC voltage	PCS airflow
Battery DC current	Control set points
Battery DC power	Auxiliary power status
Battery DC/AC efficiency	HVAC status
Battery state of charge	

ESS DAC System Implementation

The ESS DAC System uses commercial off-the-shelf (COTS) hardware and software, including National Instruments (NI) PXI modular instruments, Bloomy EnergyMAX power monitoring software, and NI DIAdem data visualization software. Physically, the ESS DAC system consists of a controller unit, a high-voltage acquisition unit, and a low-voltage, high-channel acquisition unit (Figure 2). The acquisition units contain all of the measurement and control hardware that connects directly to the ESS's power, communications, and control interfaces. They are positioned close in proximity to the ESS test unit for maximum signal integrity. The controller unit is a mobile workstation that runs the human-machine interface that the operator controls. Located a safe distance away from the ESS, it communicates to the acquisition units over a fiber optic communications link. Hence, no electrically conductive path exists between the ESS test unit and the ESS DAC units, which ensures operator safety.

Figure 2. ESS DAC System consists of a controller unit (left), a high-channel acquisition unit (middle), and high-voltage acquisition unit (right)

Signal Types

The acquisition units handle a variety of signal types for measurement, communications, and control (Figure 3). The operator measures three-phase and single-phase AC voltages and currents from the lab's step-down transformer, across the ESS line terminals, across the load, and other locations of interest within the ESS. DC voltages are measured from the battery, including the individual cell and stack voltages (if accessible), temperatures, and other signals. The acquisition unit also acquires system parameters including air flow and temperatures, and controls analog outputs and relays for system simulation. The operator can monitor and control the ESS master controller and battery management system (BMS) through optional communications, which support controller area network (CAN), Modbus, and Ethernet protocols. The operator uses isolated transducers to step the high-level voltage and currents down to low-level signals, which are safely digitized using the PXI instrumentation to maintain high accuracy, resolution, and bandwidth. High sampling rates are used in order to acquire and analyze complete AC waveform data.

Figure 3 Signals acquired by the ESS DAC units

Parameter	Channels	Max Value	Sampling Rate (Hz)	Accuracy
AC Voltage	12	1,000 V	20.0 k	±0.5%
AC Current	12	2,000 V	20.0 k	±0.5%
DC Voltage	6	1,200 V	3.0 k	±0.5%
DC Current	6	2,000 A	3.0 k	±0.5%
Battery Cell Voltages	96	14 V	10	±0.3%
Temperature	32	-230^{o} C to 400^{o} C	10	±1.0%
Airflow	2	6,000 fpm	10	±1.0%
BMS Communications	2	CAN, Modbus, Ethernet		
ESS Master Communications	1	Modbus, DNP 3.0, IEC 61850		

Software

The controller unit features a rack-mount computer and real-time controller that run EnergyMAX software as a distributed application. An acquisition engine runs deterministically on the real-time controller. It continuously acquires measurement data, updates control outputs, communicates to the BMS, and maintains synchronization of all data. The user interface is a separate application that runs on a rack-mount Microsoft Windows-based computer. The operator interactively configures and calibrates each measurement channel, and monitors the transducer data in engineering units and raw voltage or current units (Figure 4).

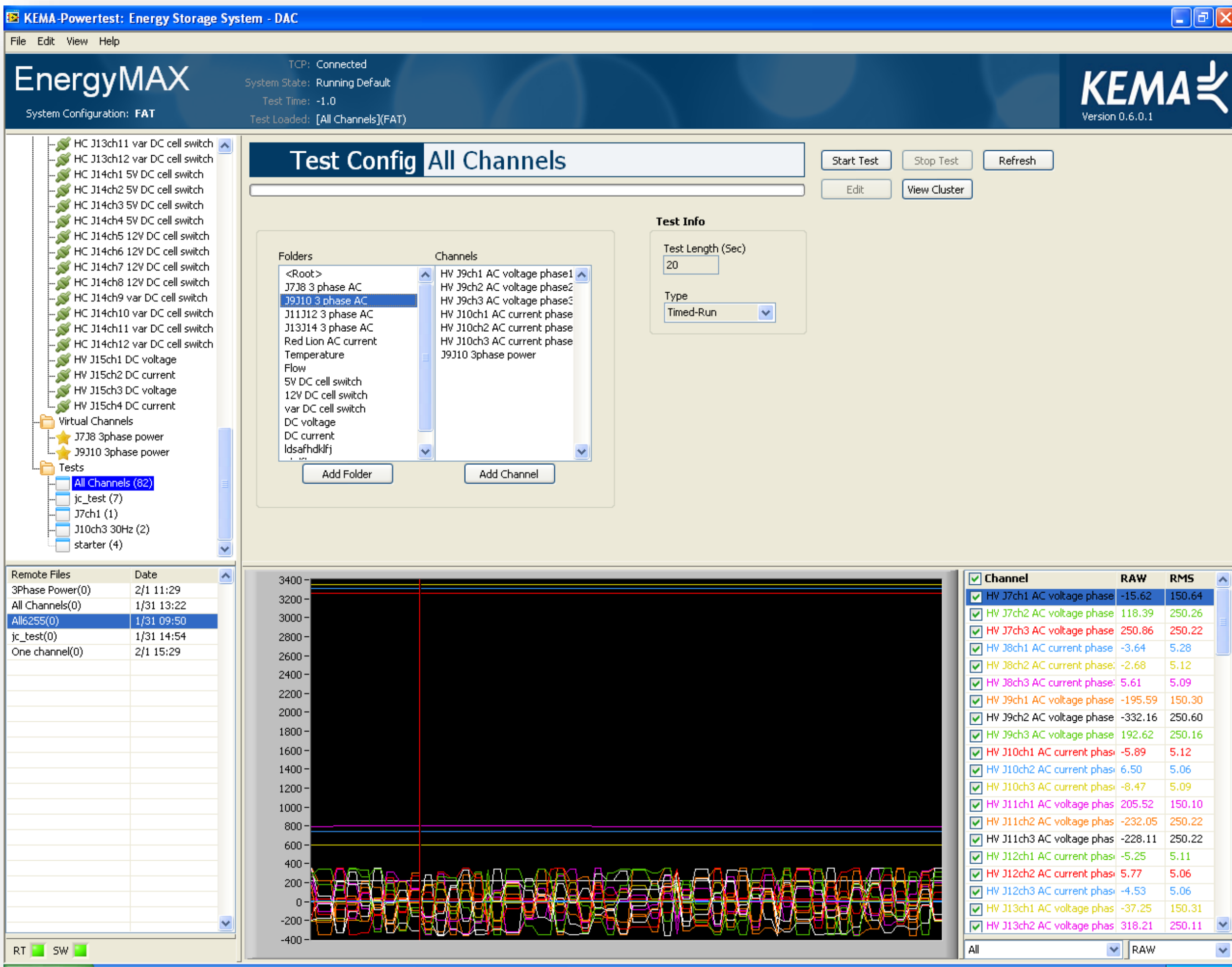

Figure 4. Software is used to configure and calibrate all measurement channels and to monitor transducer data.

The ESS DAC System provides real-time, synchronous, and deterministic measurements for AC and DC voltages and currents, general I/O, and communications. It maintains safe operation through fiber optic connections and isolation transducers, and offers measurement reliability and accuracy for flexible test lengths that range from minutes to months.

ESS Testing

ESS performance specifications and test requirements vary considerably depending on the location of deployment, size, and application. Key parameters include voltage, active power, reactive power, and energy. Additionally, the test labs create application-specific tests related to performance, safety, and environmental aspects. The end-user application helps the labs determine the required efficiency, capacity, cycle life, energy density, response time, and rate of charge and discharge.

Practical Considerations

As previously stated, the wide range of ESS technologies correlate to a wide range of applications, measurements, electrical connectivity, and digital communication protocols. The lab technicians readily configure the ESS DAC System to handle these various conditions. Specifically, the system can measure nearly any AC or DC current or voltage using transducers, and entering the parameters such as the range, scaling, units, cable, and connector type using a transducer configuration form, as shown in Figure 5. The transducer parameters are then stored in a database, and may be assigned to any of the ESS DAC System's channels with compatible connectors via the test configuration. Standard MIL-style connectors on the ESS DAC System's high-voltage and high-channel acquisition units allow fast connection of transducers, and the software simplifies the configuration of tests.

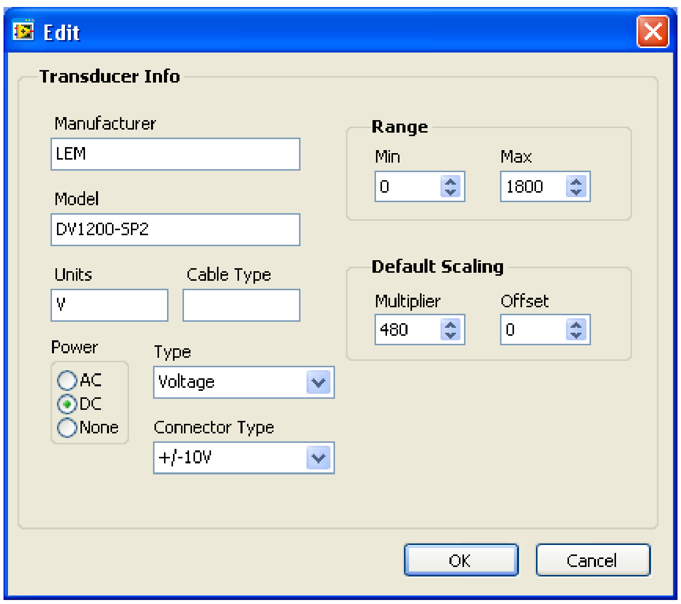

Figure 5. Current or Voltage transducer configuration form

CES Performance Evaluation

The ESS DAC System is currently being used to evaluate the safety and usable service life of a Community Energy Storage (CES) unit comprised of second life or repurposed automotive traction batteries. The testing is being performed for DTE Energy as part of the US Department of Energy's Energy Storage Smart Grid Demonstration Program. The CES consists of a power conditioning system, and a battery energy storage unit. Testing may include basic operation, round-trip efficiency, peak shaving, and frequency regulation. Figure 6 shows the test configuration at the lab. The system is powered by 480 VAC transformed down to 120 VAC. As of this writing, the tests have just begun. An update will be provided at the Battcon 2015 conference.

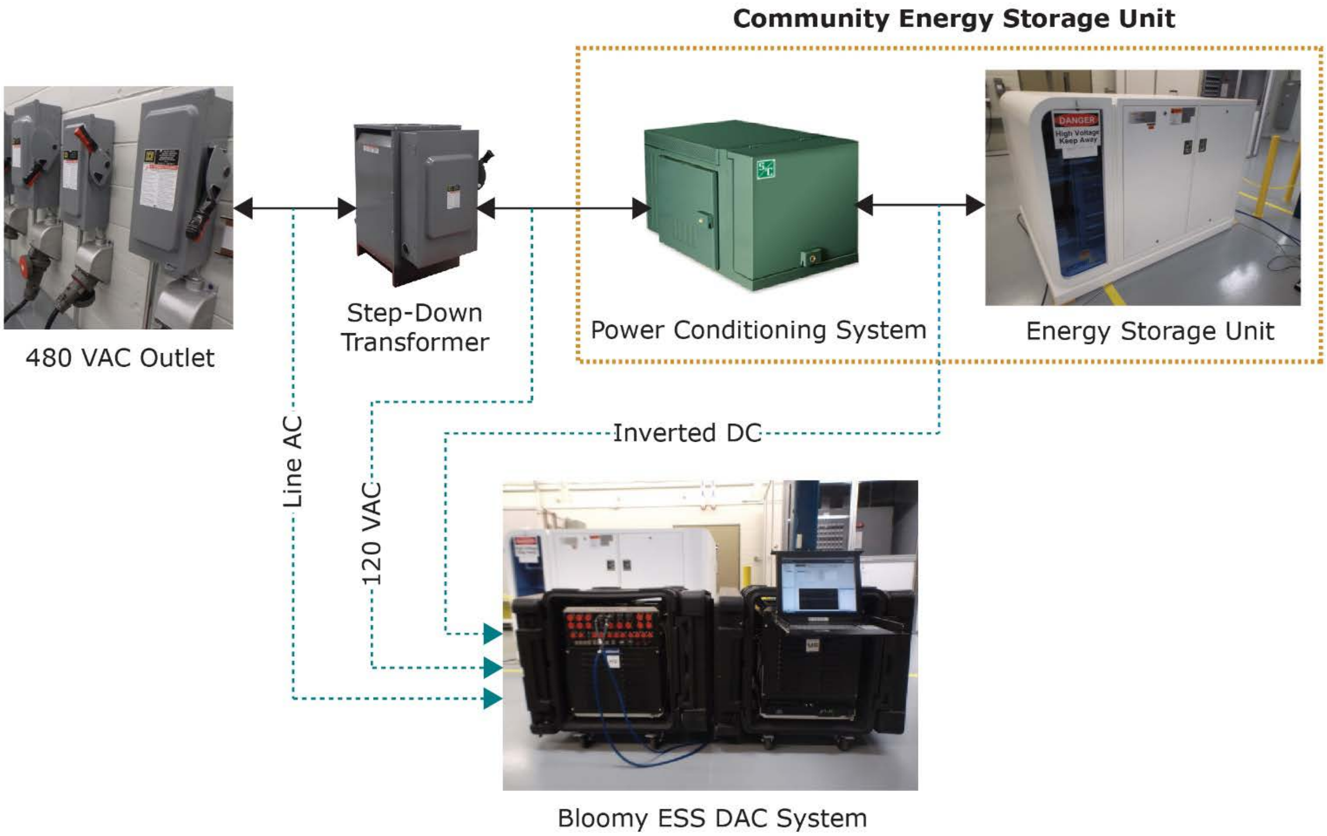

Figure 6. CES performance test setup at BEST T&CC

Conclusion

The ESS DAC System equips the BEST T&CC and DNV GL's Energy Storage Performance Test Lab with the flexibility to perform a wide range of ESS tests, from 1kW up to 2MW. The combined capabilities of Bloomy's ESS DAC System, DNV GL's expertise, and the test lab facilities are helping to aid ESS development, advance ESS performance, and accelerate ESS commercialization.

References

1. Blume, Peter; Lindenmuth, Kevin; Murray, Jonathan, "Power Grid Energy Storage Testing," EE-Evaluation Engineering, NP Communications, Sarasota, FL, November 2012 and January 2013.