Journal of Energy Storage 6 (2016) 178–185

Contents lists available at ScienceDirect

Journal of Energy Storage

journal homepage: www.elsevier.com/locate/est

Grid connected performance of a household lithium-ion battery energy storage system

M. Bila, C. Opathella*, B. Venkatesh

Centre for Urban Energy, Ryerson University, 350 Victoria Street, Toronto, ON M5B 2K3, Canada

ARTICLE INFO

Article history:
Received 4 November 2015
Received in revised form 2 April 2016
Accepted 4 April 2016
Available online 26 April 2016

Keywords:
Battery Energy Storage
Li-ion Battery
Lab Tests
Smart Grid Technology

ABSTRACT

Lithium-ion Battery Energy Storage Systems (BESS) are to be the next household electrical appliance in a smart grid environment. This is beside the growth of electrical vehicles with lithium-ion batteries. However, these batteries are yet to prove their performances in the household sector.

This paper presents the performances of a small household scale battery energy storage system with a lithium-ion battery pack and a single-phase ac-dc inverter. Results of a list of tests conducted in a lab environment are presented explaining the test procedures and results.

Test results show that the considered BESS is suitable for daily cycling applications but has low efficiencies at the rated power operations. Converter losses contribute to the low efficiency of the considered BESS. The BESS is more efficient in lower power (lower than rated) operations. However, the effects of the current harmonics need to be considered when it is operated with other appliances.

1. Introduction

Energy storage systems (ESS) are set to play a vital role in future electricity grids due to their inherent advantages in managing problems in power systems. If a distribution system has a higher penetration of intermittent renewable energy sources, energy storage systems can be used to correct power quality problems associated with the renewable energy sources. There are many energy storage technologies being discussed for different power system applications such as energy arbitrage, spinning reserve, voltage regulation, investment deferral, congestion management of transmission/distribution systems etc. [1–3]. A suitable energy storage technology is selected based on the characteristics of the energy storage technology such as energy content in a cycle, maximum power capacity, ramp rates, reactive power capability, cost etc.

Besides the applications in the utility grid level, energy storage systems are also starting to penetrate into the household consumer sector. New developments in Lithium-ion battery technologies have made this possible. Electric vehicles (EV) batteries are the best example of such ESS. Furthermore, recently one of the battery manufacturers launched their household Battery Energy Storage System (BESS) [4]. These household energy storage systems are used as either solar energy storage or backup power supply. Even though at present these Li-ion based BESS appear in EVs, off-grid houses, and cottages, in a smart grid environment, energy storage systems have a promising future as a common household electrical appliance to maximize the renewable energy generation. In a smart grid environment, it is also expected that households will be using BESS to level their loads [5]. According to the authors in Ref. [5], households who purchase the maximum amount of power at the most cost effective price utilising the maximum level of state of charge could get the most benefits. However, frequent cycling reduces the charging capacity of the battery [18]. Due to these prospects and drawbacks, it is timely important to understand the performance of BESS in grid connected household operations.

Household BESS can be based on different battery technologies. Because of new developments in Li-ion battery technologies, the cost of BESS with Li-ion batteries is reduced while achieving higher energy densities. Therefore, in this paper, only Li-ion based BESS are discussed. In Refs. [6,7], Li-ion battery characteristics have been tested for electric vehicle applications. Results of the study show that parallel connection of cells could worsen the cell degradation. Therefore, in most battery packs, cells are connected serially. This allows cells in the same battery pack to operate at different cell voltages. However, all cells in the pack must operate within their recommended voltage threshold. In Refs. [8–10], Li-ion battery performance has been tested for especially for solar applications. Availability of solar power and the efficiency of the BESS are concerns for daily cycling solar applications. One of the other major

* Corresponding author.
E-mail address: opathella@ryerson.ca (C. Opathella).

http://dx.doi.org/10.1016/j.est.2016.04.001
2352-152X/

concern is that the cycle life of a Li-ion battery depends on the charge/discharge operations of the battery. High depth of discharge (DOD) operations drastically reduce the cycle life of Li-ion batteries [24]. However, the real lifetime degradation depends on several factors. Effects of operation temperature, average state of charge (SOC), maximum DOD, previous usage and charge rate on the lifetime of Li-ion batteries are discussed in [24,25]. However, the battery lifetime degradation is not in the scope of BESS electrical performances investigation discussed in this paper.

In Refs. [11,12], authors discuss methods to improve charging efficiency. However, a wide range of other performance parameters of BESS have not been discussed and need to be researched in order to integrated Li-ion BESS as a household appliance. As an example charge/discharge cycling is different in household applications compared to the grid-connected PV or EV applications. Firstly, in order to benchmark the technical characteristics of various Li-ion household BESS from different manufacturers, test procedures need to be formulated. These tests are specifically for exploring the general performance characteristics of Li-ion household BESS. With the results of these tests, the household user will be aware of the combined performance of the battery and the converter in household applications.

This paper presents the performance of a household battery energy storage system tested in a lab environment. Firstly, in Section 2, battery test setup and the list of tests are presented. Tests were carried out in a laboratory environment as described in Section 3. Results of all tests are also presented and discussed in Section 3. The conclusion of the paper is in Section 4.

2. Test setup and selected tests

The BESS has a 3.88 kWh battery module (model KBM255-C) and a Battery Management System (BMS) both supplied by Kokam Co. Ltd. The module consists of fourteen serially connected 75 Ah cells. A single-phase inverter/charger (XW6048) manufactured by Schneider Electric, establishes the connection to the ac grid of 120 V. The nameplate data of the battery and the single phase inverter/charger is given in Table 1 [13,14]. Some of the battery ratings have overlapping limits in terms currents and power. Therefore, operating at the rated current is not possible at some voltages in the allowed voltage range due to exceeding rated power ratings. In such cases, the test setup was operated within the most restrictive limit without violating any rated limits. The schematic diagram and the actual test system are shown in Figs. 1 and 2.

The Schneider Electric inverter/charger and the BMS are connected to a Personal Computer (PC). The inverter/charger is connected to the PC through a Xanbus-Ethernet network by interfacing with Schneider Electric communication box (Conext ComBox). Whereas the BMS is directly connected to the USB port of the PC. An Acuvim IIW power meter from AccuEnergy is used to record time domain measurements (voltage, current, power, frequency etc.) at the Point of Common Coupling (PCC). Recorded parameters are then transferred to the PC through a USB cable. Using the BMS connection and associated software, battery dc voltage, dc current and SOC, as well as cells temperatures and cells voltages are readable from the PC. Both ac side and dc side power, voltage and current of BESS are recorded through the network connection and the web browser of the Combox.

A user of this BESS would like to know the parameters such as efficiency of the BESS, standby power consumption, harmonic generation etc. Following performance tests were conducted using

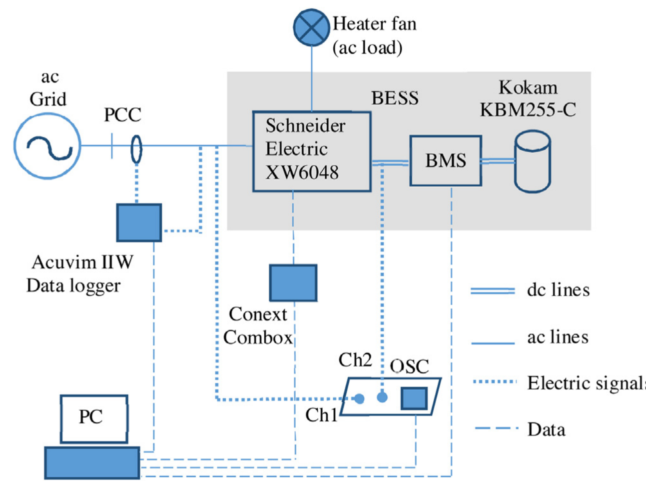

Fig. 1. Schematic diagram of the test setup.

Fig. 2. Battery energy storage lab setup.

Table 1
Name plate data of the inverter/charger and the battery [13,14].

Schneider Electric XW6048		Kokam KBM255-C	
Continuous power	6000 W	Continuous power—charge	3 kW
Voltage	120 V	Continuous power—discharge	5 kW
Frequency	60 Hz	Number of cells	14
cos phi	0.98	Cell capacity	75 Ah
Maximum efficiency	95%	Energy capacity	3.88 kWh
Input voltage limits	44–64 V dc	Operating voltage range	46.2 ~ 57.4 V
Voltage Limit—sell mode	108–130 V ac	Continuous current—charge	65 A
Voltage limit—charge mode	80 ~ 150 V ad	Peak current—charge	110 A
Maximum input current at rated power	130 A dc	Continuous current—discharge	110 A
Maximum Charging current	100 A	Peak current—discharge	150 A