MANiFEST Project

Power Profiles for the Calculation of Efficiencies of Energy Storage Systems

1 Introduction

This document lays out a set of power profiles intended to allow for the calculation of the efficiency of multi-scale energy storage systems (ESS) within the EPSRC-funded MANiFEST project. The aim of these tests is to generate a set of comparable datasets using the diversified ESSs procured and operated by MANiFEST partners. This document describes the test regimes and data formatting as performed by The University of Sheffield (TUoS).

2 System Specification

The energy storage plant operated TUoS (see Figure 1) is the Willenhall Energy Storage System (WESS), which is a 2 MW lithium-titanate (LTO) battery system. The battery is comprised of 40 parallel-connected battery racks, giving a total (nominal) capacity of 968 kWh. Each battery rack itself is made up of 22 series-connected SCiB LTO battery modules containing 24 cells in a 2P12S configuration. The battery has a nominal voltage of 610 V and an operational voltage range of 530–712 V.

WESS is interfaced directly to the power grid through an 11 kV feed, located at the Willenhall Primary Substation. This interface is achieved with a 2 MVA ABB inverter system,

which converts the variable DC battery voltage to a fixed AC voltage of 360 V, this is then fed through a 2 MVA transformer which steps the voltage up to the 11 kV supply voltage.

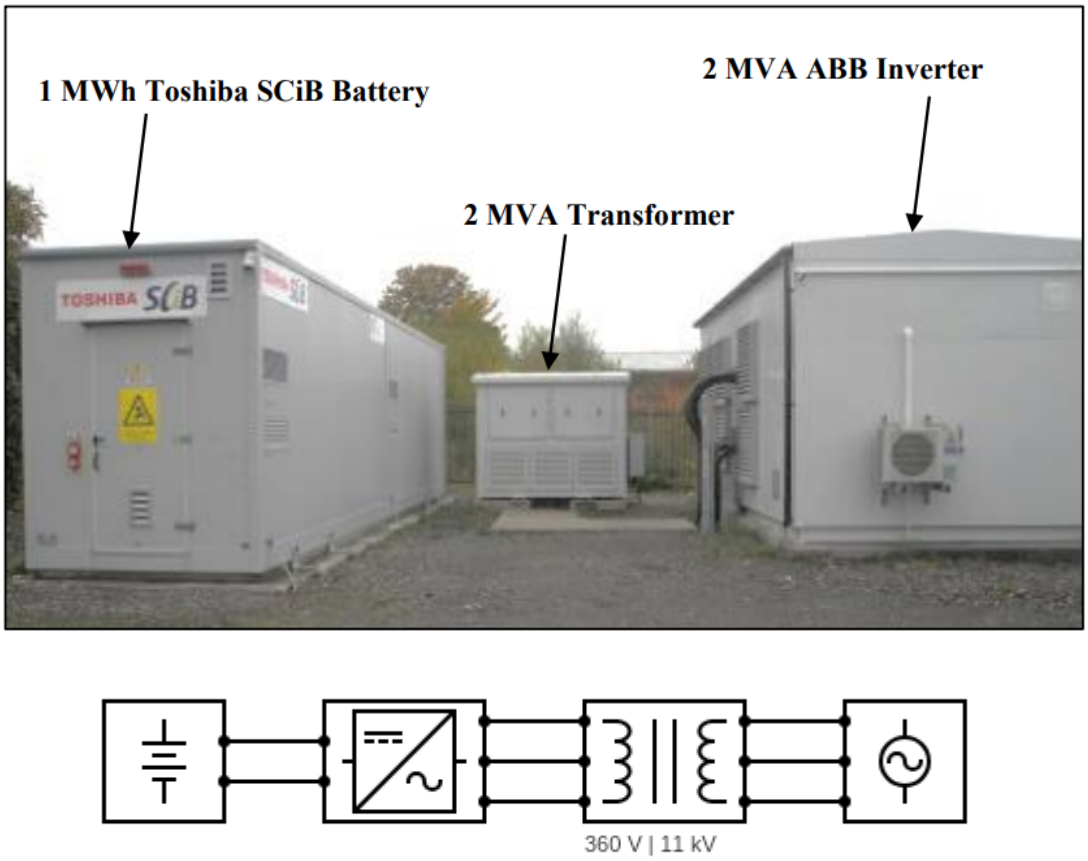

Figure 1: The Willenhall Energy Storage System (WESS)

3 Test Procedures

The objective of this testing is to determine the round-trip efficiency of the WESS and to develop a standard test procedure to allow for efficiency comparisons with the other energy storage assets operated by the MANiFEST partners. Two test procedures have been developed, to evaluate the efficiency of the systems under various modes of operation.

3.1 Test Procedure 1

Test procedure 1 is designed to measure the efficiency of the ESS when subjected to a full discharge-charge cycle. In this test a series of such cycles are applied to the ESS, and by comparing the amount of energy exported during the discharges to that imported during the charges, the round trip efficiency of the system can be determined. This mode of operation

is typical of energy storage assets which are used for energy trading; importing energy from the grid when prices are low and exporting when the price rises. Figure 2 shows an example of the power profile used in this test and the resultant voltage and State of Charge (SoC) profiles.

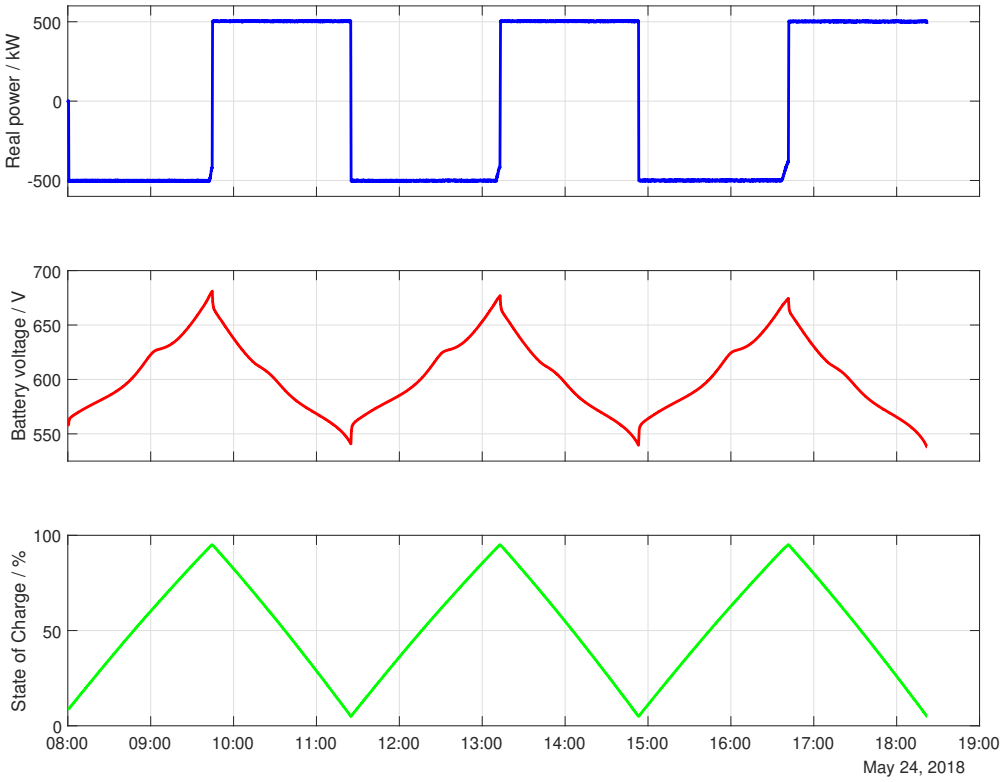

Figure 2: Test procedure 1 example power, voltage and SoC profiles

To analyse the effect of power demand on system efficiency, this test procedure should be applied several times with a range of power demands. In this instance eight power levels were examined, these being: 250, 500, 750, 1000, 1250, 1500, 1750 and 2000 kW.

3.2 Test Procedure 2

Test procedure 2 is designed to measure the efficiency of the ESS when subjected to relatively small changes in SoC occurring across the full operational range of the ESS. This style of operation is typical of assets used in a grid support role, where power demand is determined by instantaneous grid frequency.

This test consists of applying a series of seven cycles with power levels from 500–2000 kW in 250 kW increments to cause a specific change in the SoC (Δ_{SoC}) of the system from a baseline SoC. Once the cycles have been completed, the battery is discharged to a new baseline SoC and the process is repeated.

Figure 3 shows an example of the power, voltage and SoC profiles for this test procedure,

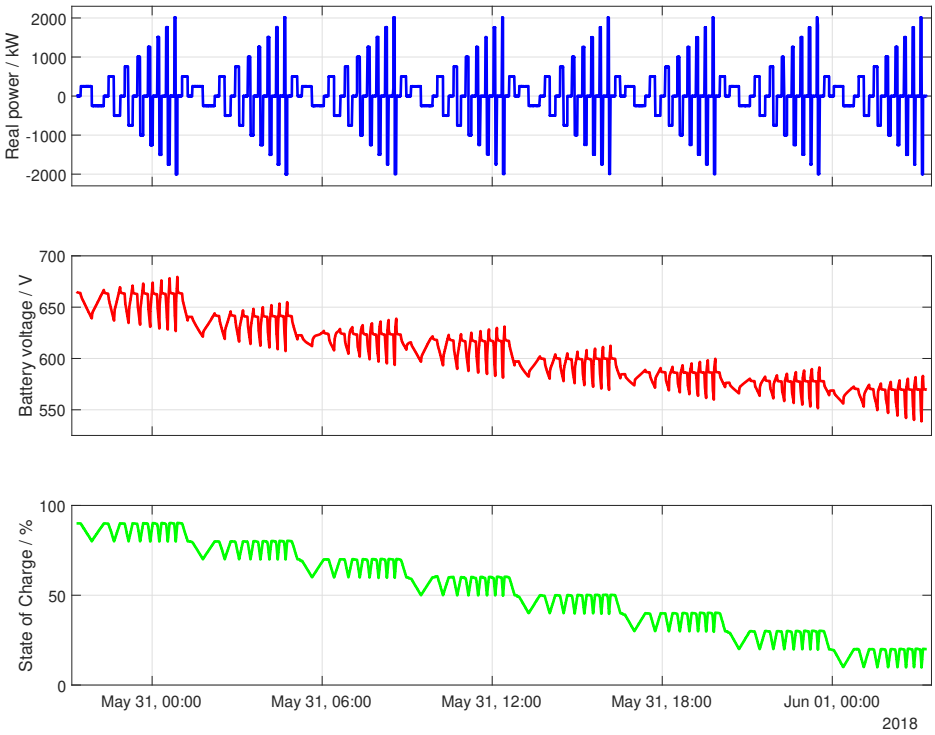

Figure 3: Test procedure 2 example power, voltage and SoC profiles

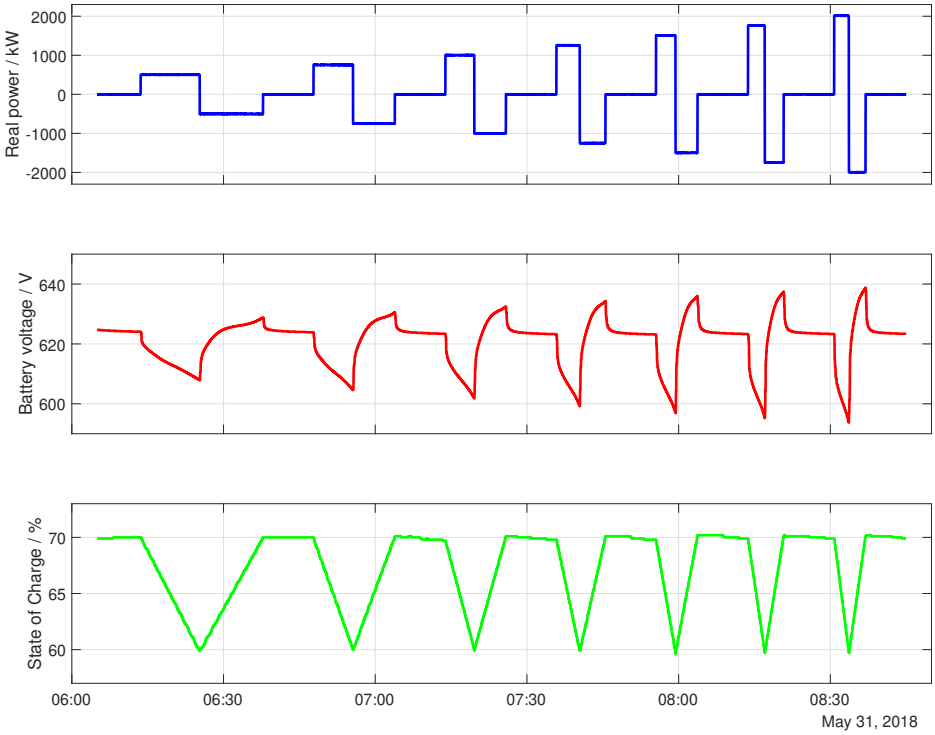

Figure 4: Test procedure 2 example profile details

whilst Figure 4 shows an enlargement of the profile for a single baseline SoC level. To provide the best picture of system efficiency, three Δ_{SoC} levels were examined: 5, 10 and 20 %. Table 1 details the specific SoC ranges examined for each test.

Δ_{SoC} (%)	SoC (%)
5	15–20, 25–30, 35–40, 45–50, 55–60, 65–70, 75–80, 85–90
10	10–20, 20–30, 30–40, 40–50, 50–60, 60–70, 70–80, 80–90
20	15–35, 25–45, 35–55, 45–65, 55–75, 65–85, 75–95

Table 1: SoC levels for Test 2

3.3 State of Charge Estimation

The above test procedures rely heavily on the SoC of the battery, particularly in the case of procedure 2. For these experiments the SoC is obtained from the battery management system (BMS) as installed by Toshiba. The inner workings of the estimation system are proprietary and therefore not fully described, it can be inferred however that coulomb-counting is used to track changes in SoC when the battery is under power, together with an open-circuit voltage (OCV) v.s. SoC correction mechanism when no power is being transferred.

This behaviour can be seen from the SoC profile in Figure 4, there are several small changes in SoC around 70 % SoC despite the battery power being zero. These changes are caused by the SoC estimation correcting itself from the known OCV–SoC relationship for the battery.

4 Efficiency Analysis

A full analysis of the system efficiency is beyond the scope of this document. Please see the metadata section for details of publications which use these datasets to determine the system efficiency.

5 Data Presentation Format

In order to follow a unified standard for data presentation, all the results obtained from this testing are presented using the comma-separated-value (CSV) format with the following columns:

- Column 1: Data-point ISO 8601 timestamp (yyyy-mm-dd hh:mm:ss.ss)
- Column 2: Grid frequency (Hz)
- Column 3: Real power, as measured by ABB inverter (kW)

- Column 4: Reactive power, as measured by ABB inverter (kVAr)
- Column 5: Battery SoC, as estimated by Toshiba BMS (%)
- Column 6: Battery DC voltage, as measured by Toshiba BMS (V)
- Column 7: Battery DC current, as measured by Toshiba BMS (A)
- Column 8: Average AC phase voltage, as measured by ABB inverter (V)
- Column 9: Average AC phase current, as measured by ABB inverter (A)
- Column 10: Battery ambient temperature, as measured by Toshiba BMS (°C)

6 Included Data Files

11 data files have been produced by this testing and are included with this report. They are named as follows: '`Test1_xxxx.csv`' and '`Test2_yy.csv`', where '`xxxx`' indicates the power level used for the cycle in kW, and '`yy`' indicates the Δ_{SoC} examined.