Project Name: MANiFEST

Description: Real and Reactive Power Profiles Intended for Calibration of Energy Storage Systems

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Introduction

This document lays out a set of real and reactive power profiles intended for calibration 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. Herein, a description of the test regimes and data formatting, as carried out between The University of Sheffield (TUoS) and The University of Manchester (TUoM), is presented.

Systems Specifications

The energy storage plant at TUoS (see Fig. 1) is called the Willenhall Energy Storage System (WESS), which is a 2 MW lithium-titanate (LTO) battery system comprised of 2 parts; each part is composed of 20 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 2 cells in parallel and 12 cells in series (2P12S) connection. WESS is interfaced directly to the power grid through an 11 kV feed, located at the Willenhall Primary Substation. The plant at TUoM (see Fig. 2) is a Siemens product marketed under the name SieStorage. The system is a 240 kVA lithium-ion polymer battery connected to the local low voltage distribution grid, with a nominal capacity of 180 kWh. The system comprises four racks where a rack consists of 14 × 48 V LG UPB 4860 modules connected in series. Table 1 and Table 2 present the electrical specifications of the two tested ESSs.

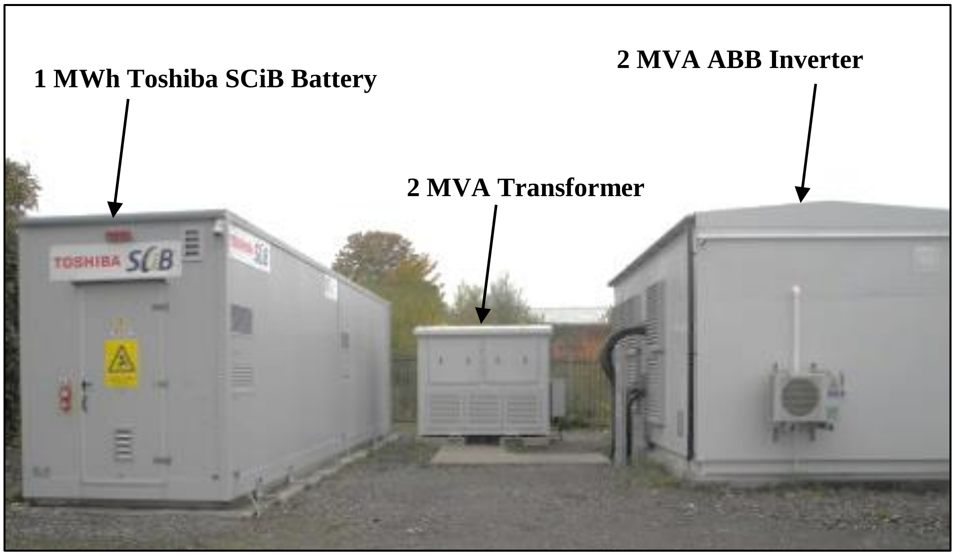

Fig. 1. The Willenhall Energy Storage System (WESS)

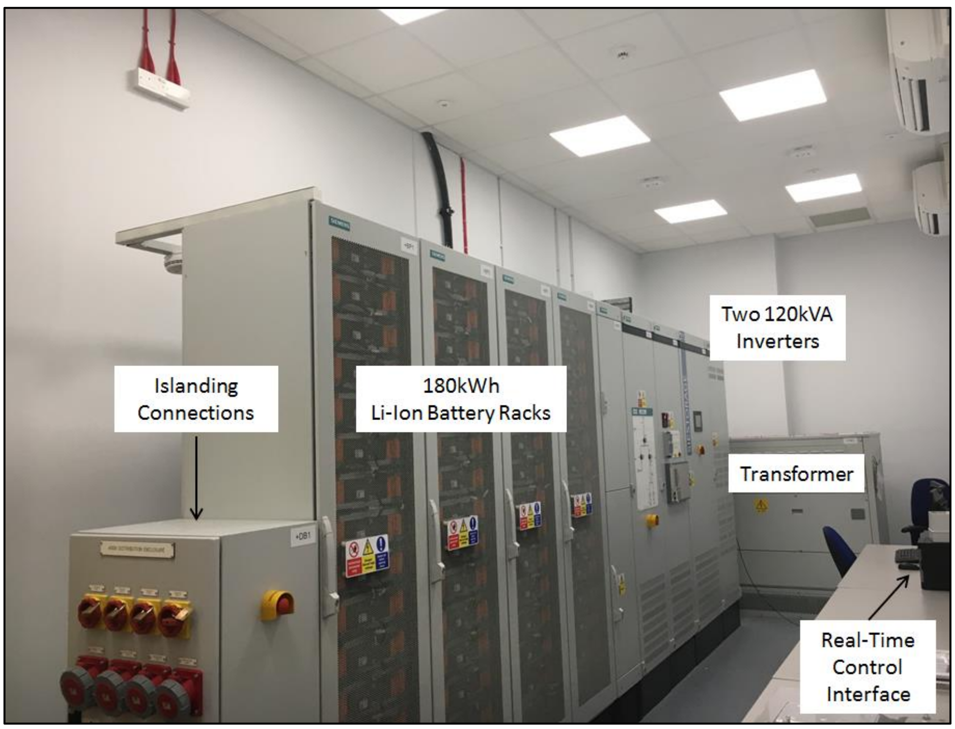

Fig. 2. The University of Manchester Energy Storage System

Table 1. Electrical specifications of the two ESSs

Parameter	**TUoS**	**TUoM**
Max real power	± 2 MW	± 240 kW
Max reactive power	± 2 MVAr	± 240 kVAr
Tx primary voltage	11 kV	400 V
Tx secondary voltage	360 V	430 V
DC bus voltage range	550-712 V	588-814 V
Max DC current	4000 A	408 A

Table 2. Specifications of the battery systems tested

Parameter	**TUoS**	**TUoM**
Energy storage type	Electrochemical	Electrochemical
Chemistry	Lithium-titanate (LTO)	Lithium-ion polymer (LiPo)
No. of strings	20	4
No. of series-connected modules in a string	22	14
Cell configuration in parallel-connected modules	2P12S	4P14S
Nominal voltage	607 V	672 V
Nominal capacity	968 kWh	179.2 kWh
BMS communication	CAN bus / Modbus	CAN bus

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Test Profile 1: Real-Power (*P*) Calibration

This test will provide a method of calibration between two or more ESSs by varying the real power (P) in Watts (W), as shown in Fig. 3. Note that from an ESS's point of view, positive power refers to discharge (export) and negative power is charge (import). Due to the near-full charge/discharge cycles, the ESS's state-of-charge (SoC) is initialised at 80%. Moreover, this test begins with positive (discharge or export) power demands in steps of 25% real power.

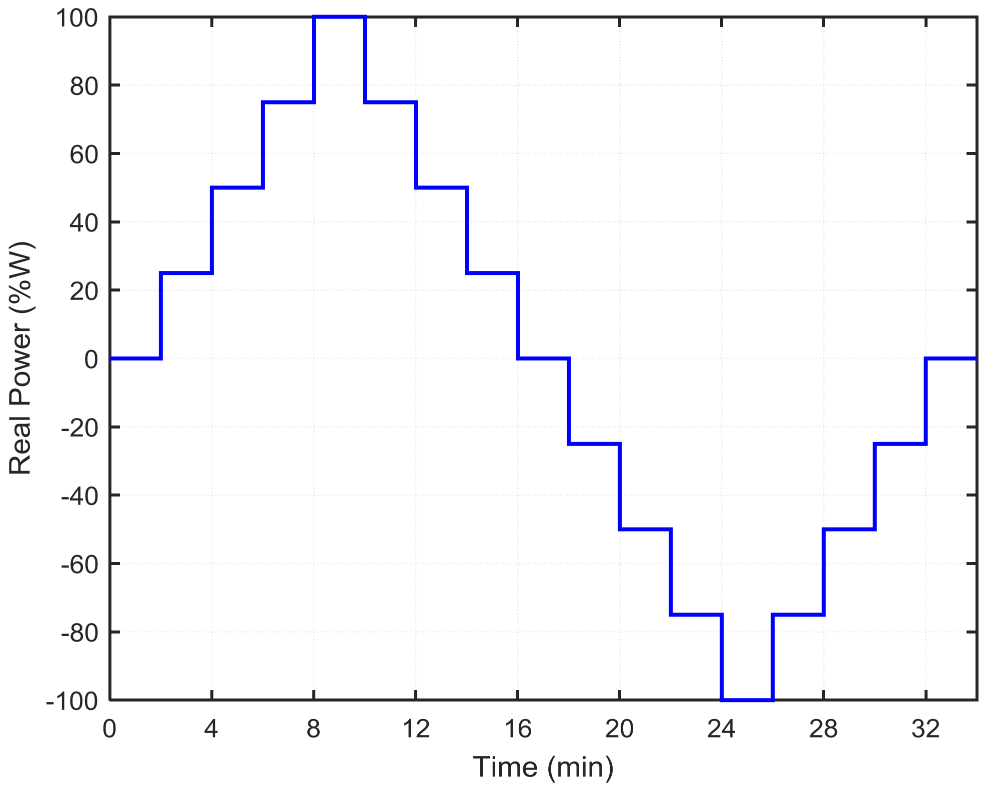

Fig. 3. Test Profile 1 – ESS real-power calibration test profile

Test Profile 2: Reactive-Power (Q) Calibration

This test will provide a means of voltage response calibration between two or more ESSs by varying the reactive power (Q), as illustrated in the power profile in Fig. 4. Note that, the same sign convention as real power applies here. During the 2-minute pulses, reactive power measured in Volt-Ampere reactive (VAr) is kept low (±10%) to avoid any potential issues with voltage swings on larger systems. Similar to the P calibration test, the ESS is initialised at a SoC of 80% prior to implementing the profile shown in Fig. 4.

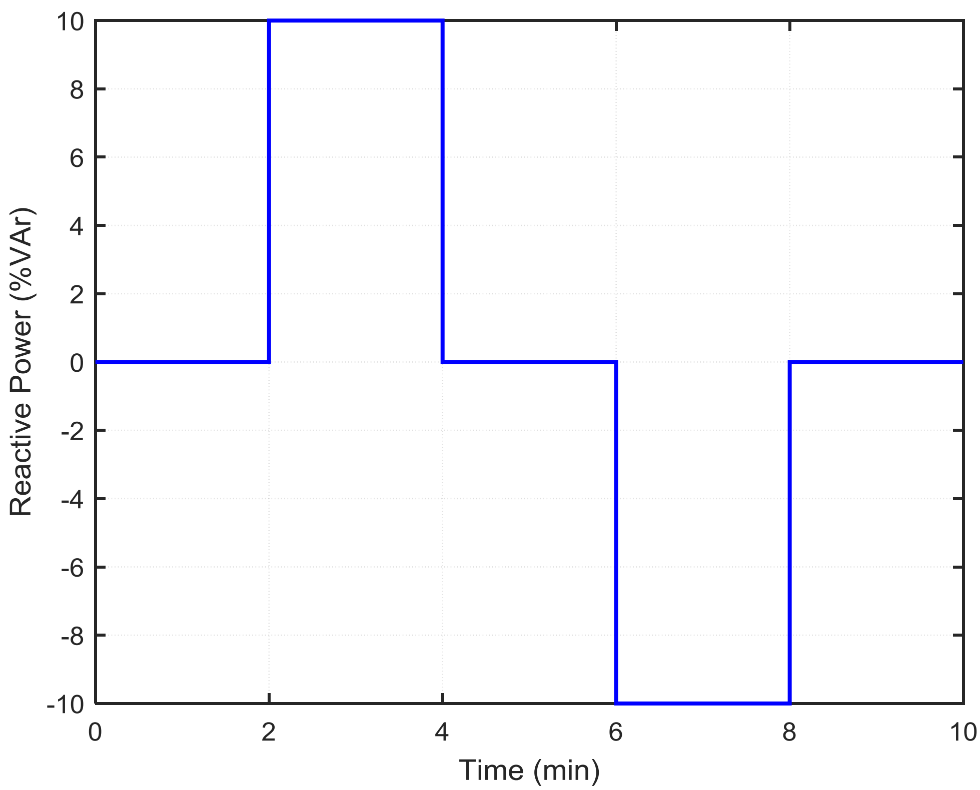

Fig. 4. Test Profile 2 – ESS reactive-power calibration test profile

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Data Presentation Format

In order to follow a unified standard for data presentation, all the results obtained from the ESS calibration tests will be presented using the comma-separated-value (CSV) format with the following column headings (also see Fig. 5):

- Column 1 – Time (dd/mm/yyyy hh:mm:ss);
- Column 2 – Frequency (Hz);
- Column 3 – Real Power (kW);
- Column 4 – Reactive Power (kVAr);
- Column 5 – State of Charge (%);
- Column 6 – DC Voltage (V);
- Column 7 – DC Current (A);
- Column 8 – Average AC Voltage (V);
- Column 9 – Average AC Current (A); and
- Column 10 – Battery Ambient Temperature (deg. C).

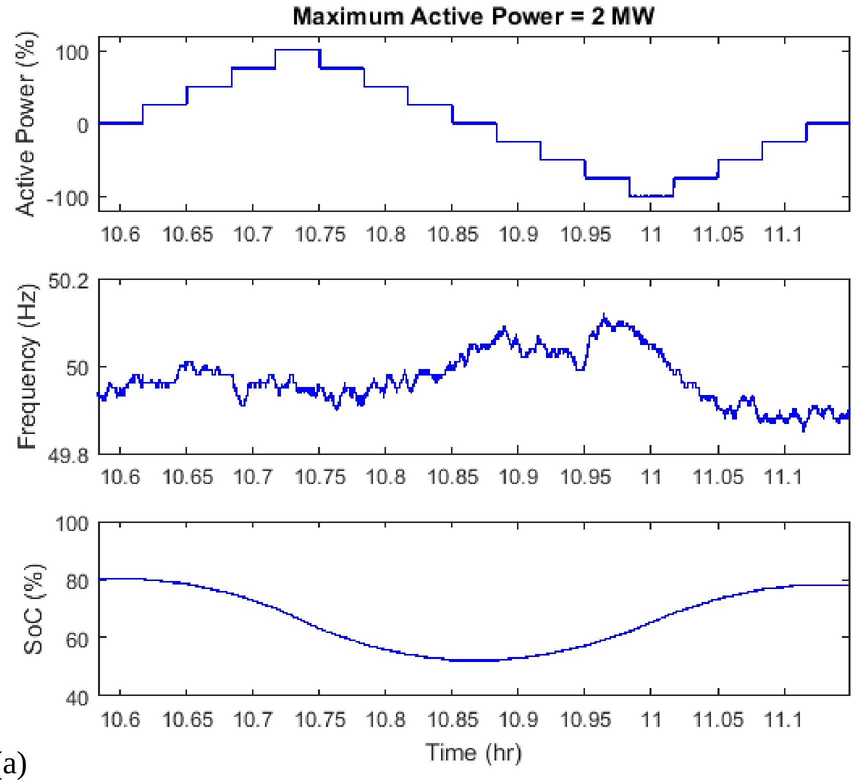
	A	B	C	D	E	F	G	H	I	J
1	Time (dd/mm/yyyy hh:mm:ss)	Frequency (Hz)	Real Power (kW)	Reactive Power (kVAr)	SoC (%)	Battery DC voltage (V)	DC Current (A)	Av. AC Voltage (V)	Av. AC Current (A)	Battery Ambient Temperature (deg.C)
2	01/03/2017 10:35:00	49.93	-3	-1	80.1	641	7	358	67	21.6
3	01/03/2017 10:35:01	49.94	-3	1	80.1	641	7	358	68.3333333	21.6
4	01/03/2017 10:35:01	49.94	-3	1	80.1	641	7	358	68.3333333	21.6
5	01/03/2017 10:35:02	49.93	-3	-3	80.1	641	7	358	68.3333333	21.6
6	01/03/2017 10:35:02	49.93	-1	-3	80.1	641	7	358	68.3333333	21.6
7	01/03/2017 10:35:03	49.93	-3	-1	80.1	641	7	358	68.3333333	21.6
8	01/03/2017 10:35:03	49.93	-3	-3	80.1	641	7	358	68.3333333	21.6
9	01/03/2017 10:35:04	49.93	-2	-1	80.1	641	7	358	68.3333333	21.6
10	01/03/2017 10:35:04	49.93	-2	-4	80.1	641	7	358.333333	68.3333333	21.6
11	01/03/2017 10:35:05	49.93	-2	-4	80.1	641	7	358.333333	68.3333333	21.6
12	01/03/2017 10:35:05	49.93	-1	-1	80.1	641	7	358.333333	68.3333333	21.6
13	01/03/2017 10:35:06	49.93	-2	-4	80.1	641	7	358.333333	68.3333333	21.6

Fig. 5. Snapshot of the CSV file as viewed in Excel

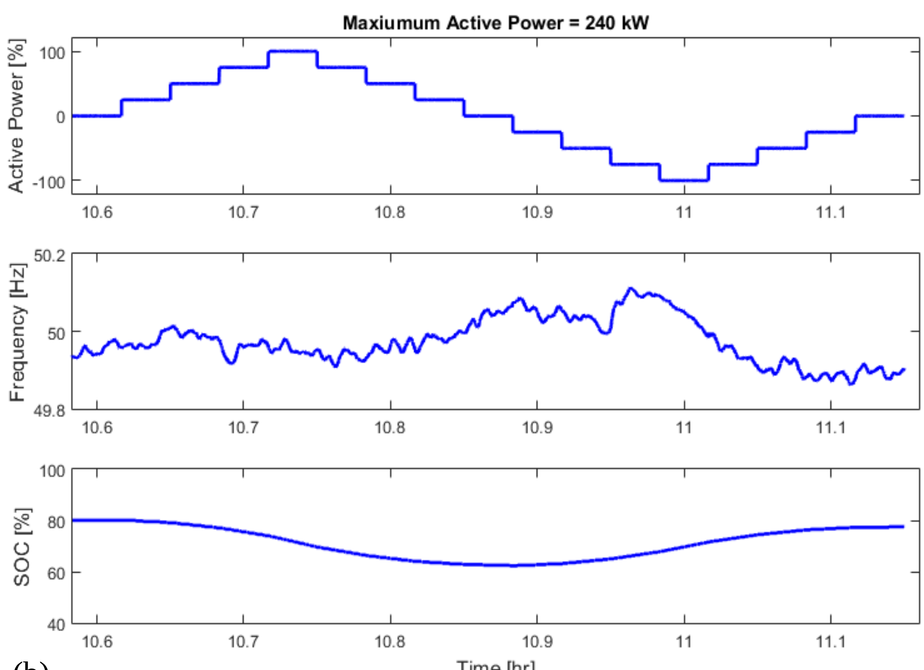
Data Visuals and Discussion

Fig. 6 presents the results for the real power calibration test data obtained from TUoS and TUoM ESSs. These plots aim to demonstrate the ability of the two systems to track their real power reference value, show the resulting SoC variation, and show the ability to record and display grid frequency (Hz) at ±0.01 Hz resolution. The measured power is displayed as a percentage of the rated maximum real power that each ESS can deliver, which is ±2 MW for the TUoS system and ±240 kW for the TUoM system. The SoC results show a sinusoidal variation over the complete test profile. One may note the slight discrepancy in the minimum SoC values achieved by the two systems and that is due to the difference in the ratio of the maximum rated real power with respect to nominal kWh capacity for the two systems in hand, resulting in a larger depth-of-discharge for the TUoS system.

Fig. 7 presents the results for the reactive-power calibration tests, as carried out on TUoS and UoM systems. These plots aim to demonstrate the capability of the two systems to provide reactive power as a means of voltage response support. Thus, a plot of the AC voltage as measured on the two systems can be found, showing ~357 V for the TUoS system and ~429 V for the TUoM system. As apparent in the SoC plots, during the reactive power calibration test, the energy consumed by the batteries is negligible (ΔSoC<1%).

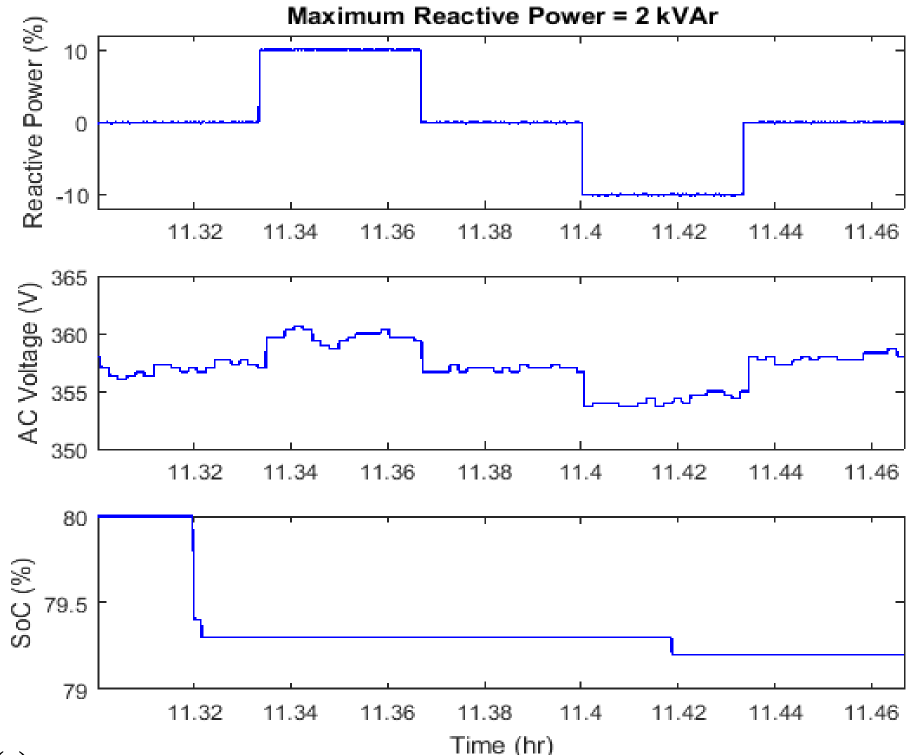


(a)

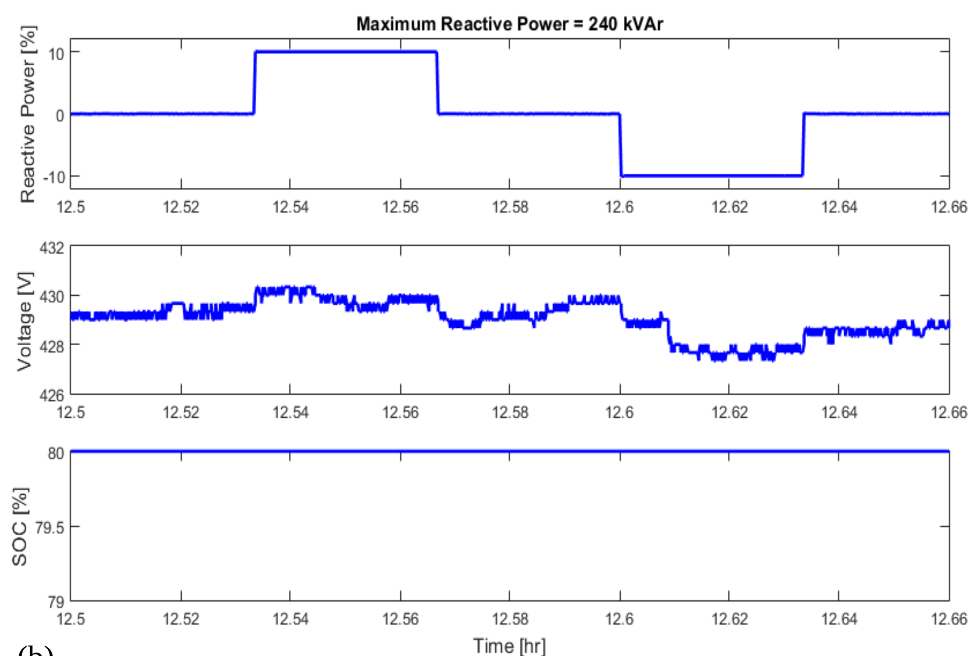


(b)

Fig. 6. Real-Power calibration test results for (a) TUoS and (b) TUoM systems



(a)



(b)

Fig. 7. Reactive-Power calibration test results for (a) TUoS and (b) TUoM systems

Conclusion

This report provided a short description of the real- and reactive-power calibration tests, intended to align ESSs within the MANiFEST project. These two calibration tests have been verified on two battery-based ESSs operated by The University of Sheffield (TUoS) and The University of Manchester (TUoM), namely the 2 MW WESS system and the 240 kW SieStorage system, respectively. The results obtained have been indicative of both systems being able to import/export both real and reactive power, in order to provide proportionate response to variations in the grid's frequency and voltage, respectively.