FEVER | Future Electric Vehicle Energy networks supporting Renewables

UKRI Engineering and Physical Sciences Research Council

Second-life battery testing

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Introduction

Batteries degrade with age. Some of this degradation is due to the passage of time (calendar ageing) and some is due to the number of charge and discharge cycles the battery has been exposed to (cycle ageing). Regardless of the source, the degradation manifests itself as a loss of battery performance as time goes on, most obviously this is presented as a loss of capacity, thus an aged battery is not able to store as much energy as a new one.

In many applications, most notably in Electric Vehicles (EVs), a battery is deemed to have reached the end of its useful life when its capacity has been reduced to around 80% of its original value. At this point the battery no longer has the capacity to perform adequately in its intended role and must be replaced.

Although an aged battery will have lost some of its performance, it still retains the ability to store energy, and if used in a less demanding application is likely to still be able to perform a useful function. This is the idea of the second-life of the battery, and involves repurposing old batteries designed for intensive high-power operations such as EVs, for use in lighter duty applications such as bulk energy storage.

Battery pack details

The pack consists of 36 battery modules connected in series to form a single string. Each module is comprised of 12, 60 Ah lithium nickel manganese cobalt oxide (Li-NMC) cells in a 4-parallel 3-series arrangement.

In the above configuration, the pack is not well suited to the FEVER application, its overall voltage is too high, and for energy storage applications multiple parallel strings of batteries are preferable over a single long string. To this end, the pack has been disassembled into individual modules. This also simplifies testing.

Results

The capacity results are summarised in the table below. This shows two key points:

- All six modules show very similar capacity figures, suggesting the pack as a whole has a similar level of degradation across the modules
- Compared to the new capacity of 240 Ah, all the modules are now to be around 80% of that value, exactly where they would be expected to be at the start of their second-life use.

Module #	Cycle 1	Cycle 2	Cycle 3	Average
01	184.2 Ah	185.2 Ah	185.6 Ah	185.0 Ah
12	184.0 Ah	184.9 Ah	185.4 Ah	184.8 Ah
24	183.1 Ah	184.1 Ah	184.6 Ah	183.9 Ah
36	185.7 Ah	186.3 Ah	186.8 Ah	186.3 Ah
98	188.6 Ah	189.4 Ah	189.7 Ah	189.2 Ah
99	185.4 Ah	186.2 Ah	186.7 Ah	186.1 Ah

The results for cell consistency are also encouraging. It can be seen from the module group voltage profiles that there is very little difference in performance, with typically less than 10 mV difference between the groups except for at the very end of discharge. This shows the cells are still well matched.

FEVER applications

The Energy Storage System (ESS) at the heart of the FEVER system is a prime candidate for the use of second life batteries. The FEVER ESS is intended to form an energy buffer, storing excess renewable generation for later consumption by charging EVs, this is a low intensity duty cycle application, where the size and weight of the energy storage is not a huge constraint. In such an scenario, second-life batteries are a sensible option.

Alongside the technical suitability of second-life batteries for a FEVER ESS, there are also sound environmental arguments for their use. There is an environmental cost to producing an EV battery, and currently there is relatively limited recycling infrastructure in place to process end-of-life batteries. By using second-life batteries as part of the FEVER system, the environmental impact of the production of those batteries is reduced, as is the total amount of waste.

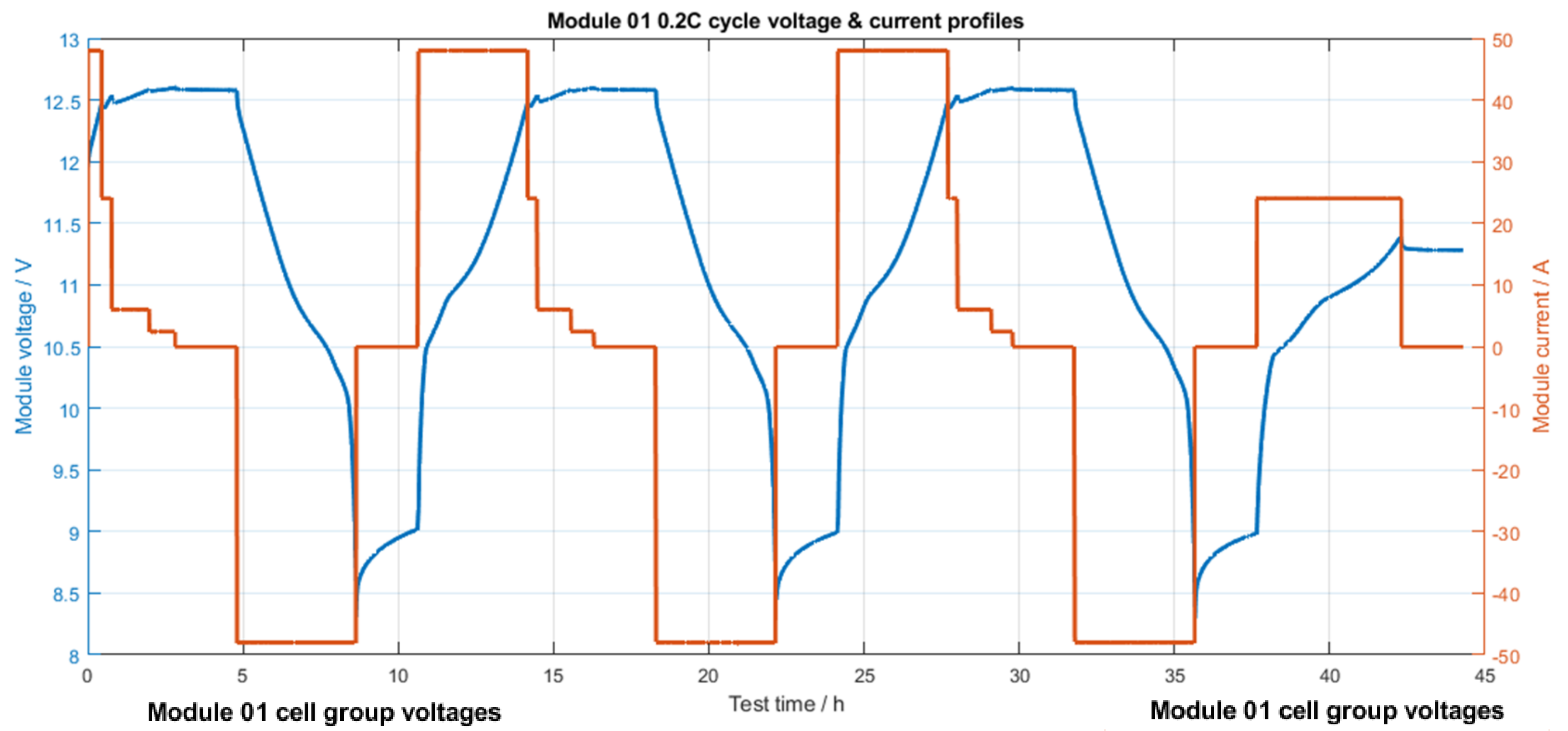
Sheffield University has an existing second-life EV battery pack. To test the suitability of these batteries for a FEVER system, and to provide real-world data for modelling and validation, a series of tests are being undertaken on the pack to determine its performance.

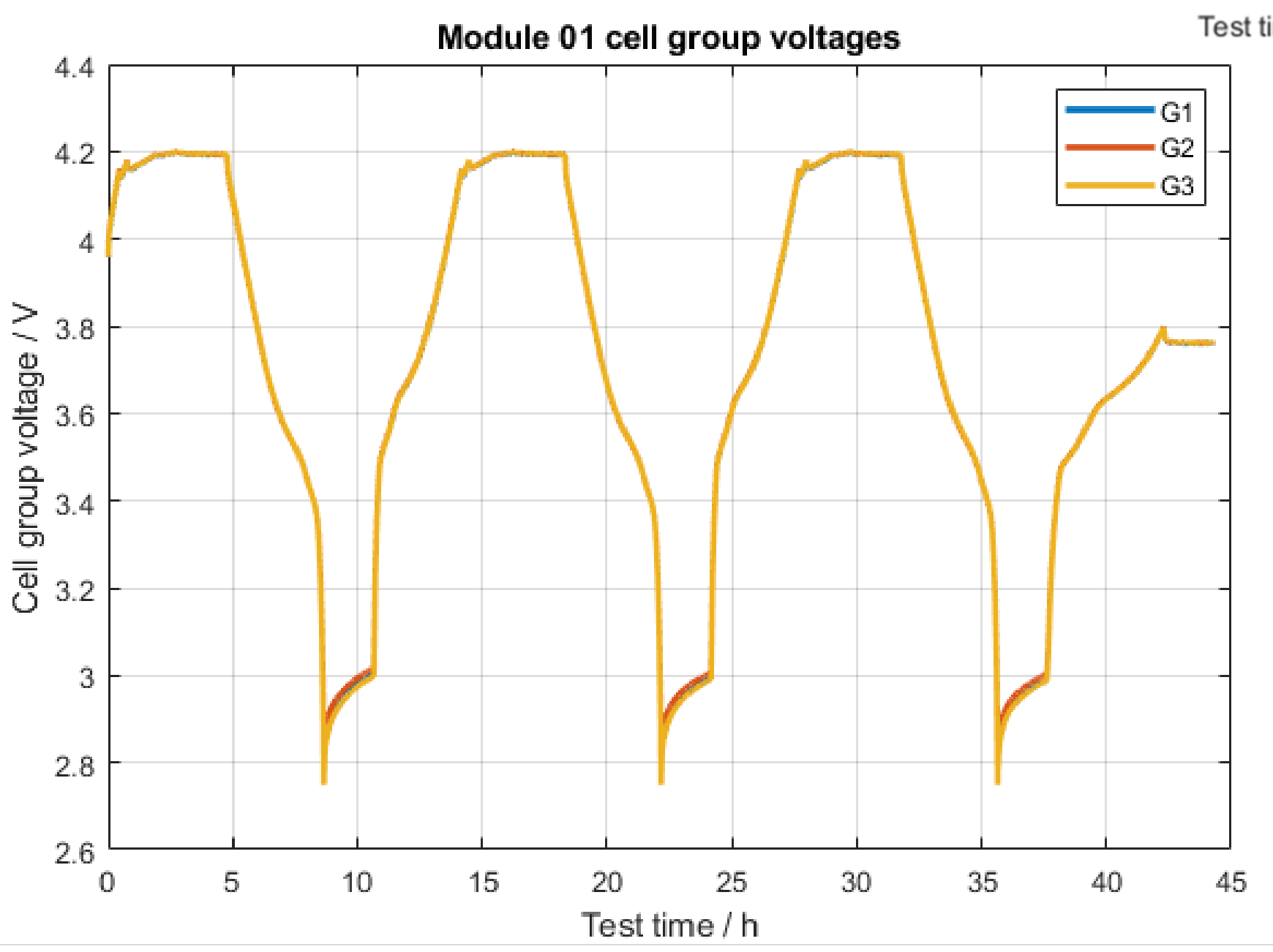
Test procedure

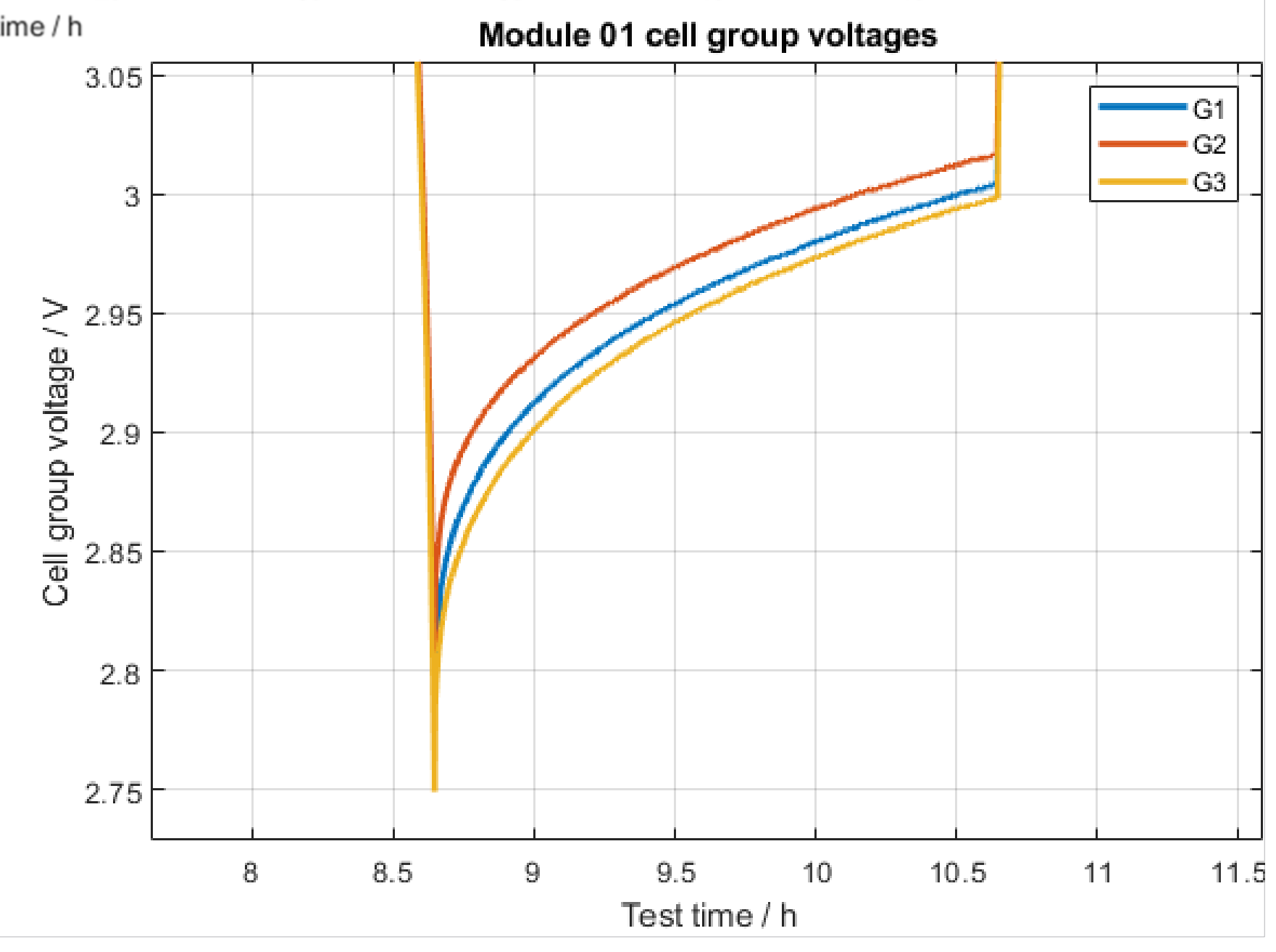
Six modules have been selected for testing, modules 01, 12, 24 & 36 from the pack itself, and two spare modules supplied along with the pack, designated modules 98 & 99. To date the testing has consisted of applying 3 cycles to the modules with a current of 48 A, equivalent to 0.2 C.

The testing has two main objectives:

- Firstly, to determine the current capacity of the modules. By comparing the experimental capacity of the modules with their known as-manufactured capacity an objective measure of their level of degradation can be determined.
- Secondly, to assess the cell consistency within the modules. As discussed above, the modules consist of 12 individual cells, and it is important that all the cells within a module have similar performance. The cells will be deliberately matched at the time of manufacture, but their behaviour may not be consistent as they age.







Further work

The testing so far has shown that the modules are well matched and appear to be in exactly the condition one would expect to receive a second-life battery in.

To test performance further requires running a similar series of tests on the individual cells within a module. This is not possible with the module assembled due to the permanent electrical connections between the cells. Therefore one module has been disassembled to allow access to the individual cells for testing.

This testing will focus on the low-level behaviour of the cells and will consider their resistance as well as capacity.

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