Statistical Analysis

This document presents the methods used so far to calculate the CoP using data from experiments series 1 - 6. It sets out the results of one particular test, showing all the experimental stages and how the CoP is derived.

After that there are some suggestions for deriving the uncertainty in the power values resulting from the load tests to start in late January. At the moment I am uncertain how much data should be recorded and how to process it to give a suitable confidence level in the results.

[From Interim Report 1 (CoP)]

Data Recorded and Calculations:

The following worked example examines in detail the various stages of one particular test run, using a 7Ah $LiFePO_4$ receiving battery and which produced the highest value of CoP in this particular group of experiments. It presents the recorded data alongside the calculations to derive the CoP value and its associated uncertainty.

Taking each sequential stage in turn:

Mains Charging:

Mains charging was done using a standard charger and the battery allowed to stabilise before a reading was taken. This value serves as the reference voltage $V_{(pk)}$ for the subsequent return of the battery to a state of full charge after pulse charging and graphical extrapolation.

Controlled Discharge:

Next the controlled discharge was undertaken using a discharge current of 3,000mA. It was decided to dissipate 20% of the battery's capacity (1.4Ah) and in Fig 1, the plot of V against t is shown, with the total Wh (energy) expended in a given time.

The value of 17.769 Wh equates to 63.97kJ (1 Wh = 3.6kJ) as shown in the accompanying spreadsheet entries in Table 1 below. The uncertainties in the values recorded will be addressed later.

At the end of the discharge stage the 'live value' of 13.07 (top right in Fig 1) showed the voltage starting to recover after the electronic load was switched off. This is to be expected as the voltage drop, due to the internal resistance of the battery, was no longer occurring. The important values are the energy expended in Wh (J) and also the stabilised final voltage measured after a 10 min rest period, in this case 13.22V. The discharge data was also made available as a CSV file and in CBA files that can be reloaded into the software for further analysis. Table 1 below shows the discharge values for a series of tests.

Fig 1: Controlled Discharge Results

Test No.	Capacity (Ah)	Current (mA)	Start Voltage [1] (V_i)	Energy Discharge (Wh)	Energy Discharge (J) [2]	% Ah	Final Voltage [3] (V_f)	CBA Test ID	Screengrab File	Comments
	Blue - data input		*Red - Auto Fill/Calculations*							
	Receiving Battery (ID:B3) - Discharge									
1	7	3,000	13.53	17.751	63,904	20.0	13.23	*181022_Discharge_1-1.bt2*	*181022-Discharge End 1*	*1 x $LiFePO_4$ - PRF Test*
2	7	3,000	13.32	17.769	63,968	20.0	13.20	*181022_Discharge_1-2.bt2*	*181022-Discharge End 2*	*1 x $LiFePO_4$ - PRF Test*
3	7	3,000	13.33	17.780	64,008	20.0	13.22	*191022_Discharge_1-1.bt2*	*191022-Discharge End 1*	*1 x $LiFePO_4$ - PRF Test*
4	7	3,000	13.32	17.769	63,968	20.0	13.22	*191022_Discharge_1-2.bt2*	*191022-Discharge End 2*	*1 x $LiFePO_4$ - Coil V Test*
5	7	3,000	13.33	17.714	63,770	20.0	13.22	*201022_Discharge_1-1.bt2*	*201022-Discharge End 1*	*1 x $LiFePO_4$ - Coil V Test*
6	7	3,000	13.32	17.734	63,842	20.0	13.21	*201022_Discharge_1-2.bt2*	*201022-Discharge End 2*	*1 x $LiFePO_4$ - Coil V Test*
7	7	3,000	13.33	17.687	63,673	20.0	13.22	*211022_Discharge_1-1.bt2*	*211022-Discharge End 1*	*1 x $LiFePO_4$ - Coil V Test*

Table 1: Discharge Data

Pulse Charging:

Now that a known amount of energy has been dissipated from the receiving battery, with a starting voltage of 13.32V and a final voltage of 13.22V, in the next pulse charging stage, we monitor the changing voltage during pulse charging while also measuring factors to calculate the energy delivered to the generator by the PSU in order for the receiving battery to be returned to a state approaching full charge.

However, as previously stated, using HV pulses directly on the receiving battery, rather than via the Capacitive Discharge circuit used in other experiments, resulted in the measured battery voltage being artificially raised for the duration of the generator ‘run time’, as is seen above in the charging monitor profile (Fig 2). This is due to the ‘surface charge’ effect at the electrodes and is the reason for the 10 min stabilisation period to let the battery chemistry settle after its exposure to >1kV pulses.

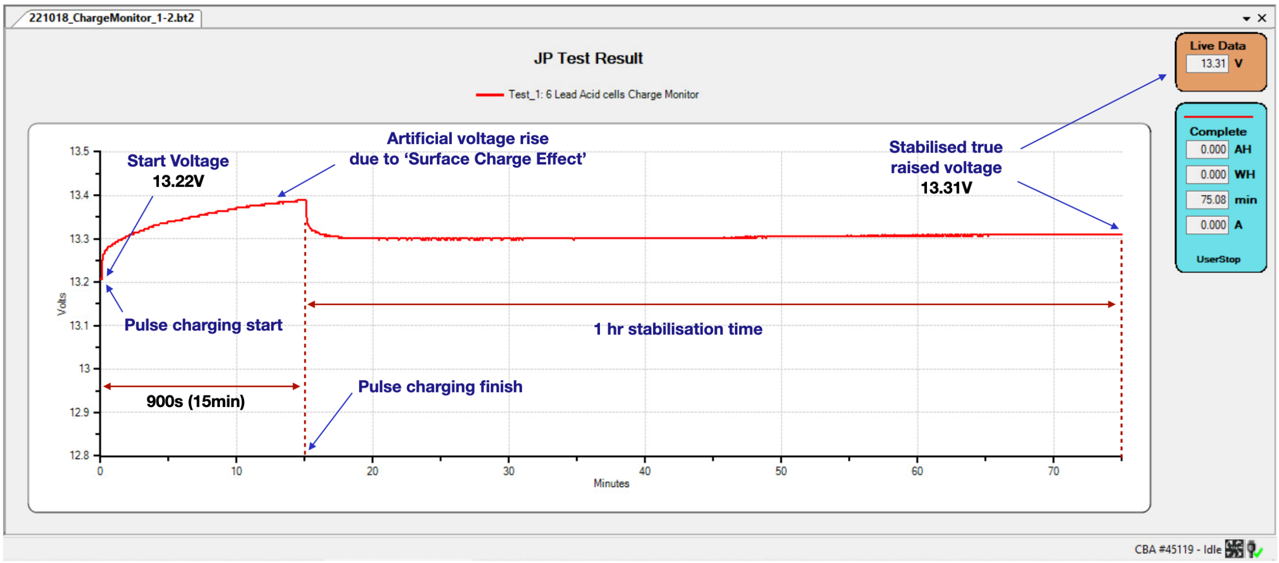

Fig 2: Vt graph during pulse charging

In order to get around this ‘artefact’, a procedure was enacted whereby a partial recharge was undertaken, using an estimated run time, and the energy required to reach full charge is obtained by extrapolating a graph of ‘Receiving battery voltage’ vs ‘Energy supplied’. This is shown further down.

During the pulse charging, the CBA’s ‘Charge Monitor’ function was used to chart the receiving battery’s voltage over time as it was exposed to the HV pulses from the generator. A typical recorded charging profile, shown in Fig 2, has been annotated with the key reference points including the ‘Run’ time duration, the enhanced voltage during

	Receiving Battery (ID:B41) - Charging (Incremental)								
Test No.	**Capacity (Ah)**	**HV (kV)**	**E Discharge (J)**	**$V_{(pk)}$ (V) [1]**	**Start Volt (V_i) [2]**	**Final Volt (V_f) [2]**	**dV (V)**	**CBA Test ID**	**Screengrab Files**
1	7	1.04	63,904	13.53	13.23	13.31	0.08	*181022_ChargeMonitor_1-1.bt2*	*181022-Charge Monitor End 1*
2	7	1.04	63,968	13.32	13.20	13.31	0.11	*181022_ChargeMonitor_1-2.bt2*	*181022-Charge Monitor End 2*
3	7	1.04	64,008	13.33	13.22	13.31	0.09	*191022_ChargeMonitor_1-1.bt2*	*191022-Charge Monitor End 1*
4	7	1.04	63,968	13.32	13.22	13.31	0.09	*191022_ChargeMonitor_1-2.bt2*	*191022-Charge Monitor End 2*
5	7	1.04	63,770	13.33	13.22	13.30	0.08	*201022_ChargeMonitor_1-1.bt2*	*201022-Charge Monitor End 1*
6	7	1.04	63,842	13.32	13.21	13.30	0.09	*201022_ChargeMonitor_1-2.bt2*	*201022-Charge Monitor End 2*
7	7	1.04	63,673	13.33	13.22	13.31	0.09	*211022_ChargeMonitor_1-1.bt2*	*211022-Charge Monitor End 1*

Table 2: Charging data

charging, the 10 mins stabilisation period and the start and stablised finish voltages. At the end of the stabilisation period we have a realistic value of the voltage rise after the assimilation of the pulsed charging. Examples of data and the test being examined (highlighted) are shown in Table 2.

In the pulse charging stage the energy to the generator is supplied by a power supply standing in for the the 'run' battery which made it easier to supply and determine a stable voltage. To calculate the total energy supplied to the generator, the average current supplied needs to be measured along with the supply voltage and the generator run time.

Test No.	**4**	
Interval	**1m**	
Data Point	**I (A)**	
1	0.7772	0.7753
2	0.7778	0.7748
3	0.7783	0.7744
4	0.7780	0.7741
5	0.7773	0.7735
6	0.7766	0.7734
7	0.7762	0.7731
8	0.7753	
Mean:	**0.78**	
SD:	0.00	
Min	0.7731	
Max	0.7783	
Range	0.01	
Δ_I	0.00	
δ_I	0.00	
Notes	$\delta_I = \Delta_I / \mu$ *(Uncertainty / Average)*	

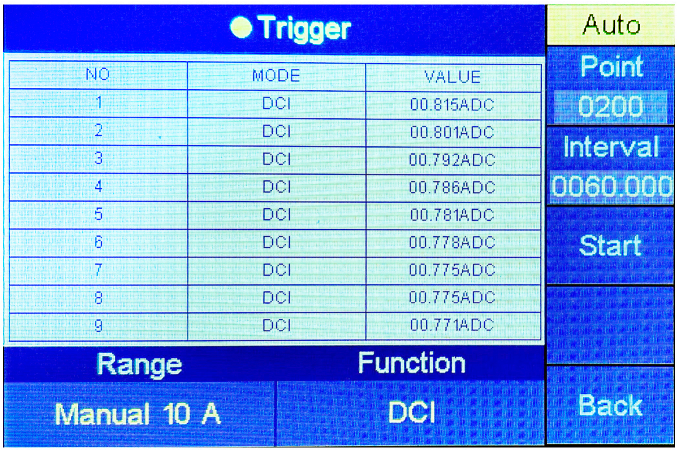

Fig 3: Supply current data & sample RDM screen

Current supplied:

The value of the current supplied to the generator by the run battery was provided from the mean of a series of current values automatically recorded every 60s by the RDM device and later exported. An example of the data is shown in Fig 3.

The voltage supplied to the circuit, kept reasonably constant for the benefit of components, the adjustable voltage applied to the coils, the average total supply current and the run time (in seconds) were used to calculate the energy supplied by the run battery using an algorithm that incorporated the different circuit and coil voltages. This is simplified as:

Run Battery (PSU) - Supply										
Test No.	PRF (Hz)	%Duty	Supply V (V) [1]	Circuit Current (A) [2]	Circuit Power (W)	Coil V (V)	I_{av} (A) [3]	Run Time (s)	$E_{(Supplied)}$ (J) [4]	RDM Imaging/Export File
1	100	65	12.50	0.098	1.23	13.0	0.90	900	10,486	*181022-Current Table 1*
2	108	65	12.50	0.099	1.24	13.0	0.90	900	10,485	*181022-Current Table 2*
3	116	65	12.50	0.097	1.21	13.0	0.88	900	10,252	*191022-Current Table 1*
4	108	65	12.50	0.095	1.19	12.50	0.78	900	8,775	*191022-Current Table 2*
5	108	65	11.48	0.095	1.09	12.00	0.66	900	7,084	*201022-Current Table 1*
6	108	65	12.31	0.095	1.17	12.30	0.73	900	8,082	*201022-Current Table 2*
7	108	65	12.71	0.096	1.22	12.70	0.83	900	9,488	*211022-Current Table 1*

Table 3: Supply data

$E_{(Supplied)} = V_{(av)} \, . \, I_{(av)} \, . \, t_{(Run)}$ J (*Equation 1)*

These are shown in Table 3 below for a range of tests together with the data used in the example calculation.

Calculating Total Energy Supplied:

As previously mentioned, the run time is any reasonable value which results in the substantial recharge of the battery. The energy delivered and voltage rise was then plotted on a graph to enable the energy supplied to the generator, for the receiving battery to reach the starting energy level at a voltage of $V_{(pk)}$, to be determined by extrapolation. A run time of 900s (15min) was found to be a good compromise for many tests, although some experiments were conducted with longer times.

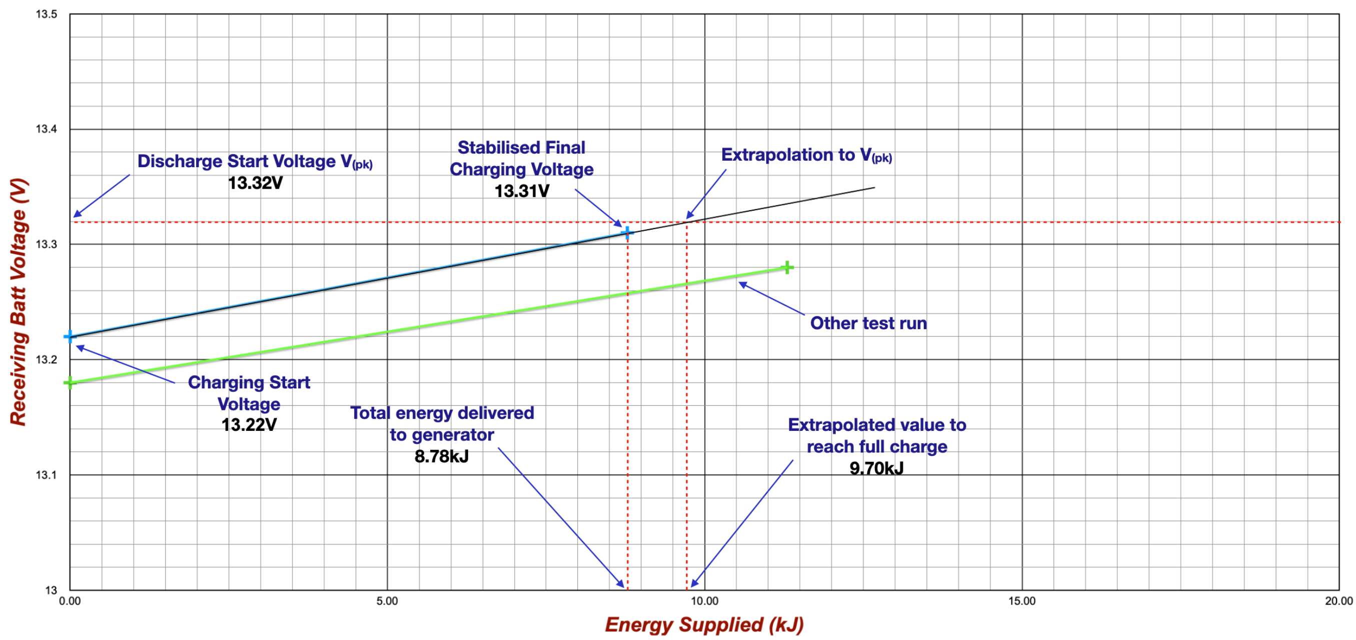

Fig 4: Receiving battery voltage vs Energy supplied

In Fig 4 the blue plot line, with the thin black extension line overlaid, is the actual pulse charging undertaken and where a total of 8.78kJ was actually supplied by the PSU (see Table 3). The stabilised charging end voltage of 13.31V was extrapolated to the ‘Discharge start voltage’ of 13.32V (the reference value $V_{(pk)}$) to give an energy value for full charge of 9.70kJ.

For comparison, the graph of another test, using different variables, is shown in green.

The extrapolation process assumes that the stabilised voltage of the receiving battery is a linear function of the energy supplied to it by the generator. While this is not strictly true, the consistent method of extrapolation used enabled CoP values to be obtained under a wide variety of operating conditions and on the basis that the assumption would constitute a systematic error that would be integrated into the load tests. The calculation of the uncertainties, incorporating most of the random and systematic errors, is discussed below.

CoP Calculations:

Now that we have values for both the energy returned to the receiving battery, to return it to the state of charge at the start of this particular test, and the energy supplied to the generator in order to achieve that, we can now derive the CoP as the quotient of the two values i.e. **CoP = $E_{(Received)}$ / $E_{(Supplied)}$.**

	Receiving Battery - CoP & Uncertainties																
Test No.	**Capacity (Ah)**	**%Ah**	**HV (kV)**	**PRF (Hz)**	$E_{(Received)}$ kJ	Δ_{Er} (kJ)	δ_{Er}	$E_{(Supplied)}$ kJ [1]	δ_V V	δ_I A	δ_t s	δ_{Es}	Δ_{Es} J [2]	CoP	δ_{CoP}	Δ_{CoP}	**CoP ± Δ_{CoP}**
1	7	20.0	1.04	100	63.90	0.36	5.63E-03	39.50	8.00E-03	1.11E-02	5.56E-04	1.97E-02	777	**1.62**	2.53E-02	0.04	**1.62 ± 0.04**
2	7	20.0	1.04	108	63.97	0.36	5.63E-03	11.50	8.00E-03	1.11E-02	5.56E-04	1.97E-02	226	**5.56**	2.53E-02	0.14	**5.56 ± 0.14**
3	7	20.0	1.04	116	64.01	0.36	5.62E-03	12.50	8.00E-03	1.14E-02	5.56E-04	1.99E-02	249	**5.12**	2.55E-02	0.13	**5.12 ± 0.13**
4	7	20.0	1.04	108	63.97	0.36	5.63E-03	9.70	8.00E-03	1.28E-02	5.56E-04	2.14E-02	207	**6.59**	2.70E-02	0.18	**6.59 ± 0.18**
5	7	20.0	1.04	108	63.77	0.36	5.65E-03	9.60	8.71E-03	1.52E-02	5.56E-04	2.44E-02	234	**6.64**	3.01E-02	0.20	**6.64 ± 0.20**
6	7	20.0	1.04	108	63.84	0.36	5.64E-03	9.80	8.12E-03	1.37E-02	5.56E-04	2.24E-02	219	**6.51**	2.80E-02	0.18	**6.51 ± 0.18**
7	7	20.0	1.04	108	63.67	0.36	5.65E-03	11.50	7.87E-03	1.20E-02	5.56E-04	2.05E-02	235	**5.54**	2.61E-02	0.14	**5.54 ± 0.14**
8																	
Equations	$E_{(Supplied)} = V_{(av)} \cdot I_{(av)} \cdot t_{(Vpk)}$ J						$\delta_V = \Delta_V / V$, $\delta_I = \Delta_I / I$, $\delta_t = \Delta_t / t$			$\delta_{Es} = (\delta_V + \delta_I + \delta_t) = \Delta_{Es} / E_{(Supplied)}$				$\Delta_{Es} = (\delta_V + \delta_I + \delta_t) \times E_{(Supplied)}$ J			
Equations	$\delta_{Er} = \Delta_{Er} / E_{(Received)}$						**CoP = $E_{(Received)} / E_{(Supplied)}$**			$\delta_{CoP} = (\delta_{Er} + \delta_{Es})$				$\delta_{CoP} = \Delta_{CoP} / CoP \therefore \Delta_{CoP} = \delta_{CoP} \times CoP$ J			
Notes	[1] *Derived from extrapolation or interpolation of Graph 1 - ‘Receiving’ battery voltage vs ‘$E_{(Supplied)}$’*																
Notes	[2] *The uncertainty value Δ_{Es} used is the larger computational value rather than the graphical value of 100J derived from plotting and reading the graph of ‘Receiving’ battery voltage vs ‘$E_{(Supplied)}$’*																

Table 4: CoP derived values and uncertainties

The data acquired is summarised below and Table 4 displays the test data for a set of experiments. A summary of the measurements obtained for this particular test run is given below.

Test Run Data Summary:

1. The fully charged 7Ah receiving battery was discharged from a voltage of 13.32V to 13.22V with 63.97kJ being expended through the electronic load.

2. The receiving battery was pulsed charged for 900s (15min), at a PWM frequency of 108Hz and 65% duty cycle, which raised its stabilised voltage from 13.22V to 13.31V.

3. In returning the receiving battery to a voltage of 13.31V, the run battery (PSU) supplied 8.78kJ of energy to the generator. This value was then extrapolated to give a value of 9.70kJ to return the receiving battery to its original full charge starting voltage ($V_{(pk)}$) of 13.32V. At that voltage the energy returned to the battery is the same as that discharged, i.e. 63.97kJ.

4. The CoP was calculated as ‘Energy received’ / ‘Energy supplied’ and therefore as 63.97 / 9.70 = 6.59. The uncertainties were calculated to give 6.59 ± 0.18 and therefore a CoP in the range 6.41 - 6.77.

While it is useful to plot the CoP value against PRF and other variables to note trends, it is equally useful to derive a value for the available external power that can be drawn from the supply battery while not depleting either battery. This is done by calculating the difference between the energy supplied by the run battery to the generator and the total energy returned to the receiving battery. This value, divided by the time taken to reach full charge,

Test No	Capacity (Ah)	Coil V (V)	PRF (Hz)	%Duty	HV (kV)	Energy Returned to battery (kJ) [1]	Energy Supplied to Generator (kJ) [2]	CoP	Energy Available (kJ) [3]	Time Taken (min) [4]	Max Power available (W) [5]
1	7	13.0	100	65	1.04	63.90	39.50	1.62 ± 0.04	24.40	56.25	7.2
2	7	13.0	108	65	1.04	63.97	11.50	5.56 ± 0.14	52.47	16.36	53.4
3	7	13.0	116	65	1.04	64.01	12.50	5.12 ± 0.13	51.51	18.33	46.8
4	7	12.50	108	65	1.04	63.97	9.70	6.59 ± 0.18	54.27	16.67	54.3
5	7	12.00	108	65	1.04	63.77	9.60	6.64 ± 0.20	54.17	20.63	43.8
6	7	12.30	108	65	1.04	63.84	9.80	6.51 ± 0.18	54.04	18.33	49.1
7	7	12.70	108	65	1.04	63.67	11.50	5.54 ± 0.14	52.17	18.33	47.4
8	7	12.50	108	65	1.04	31.36	10.25	3.06 ± 0.10	21.11	17.14	20.5
Notes	[1] Equivalent to energy discharged from ‘Receiving’ battery							[2] Extrapolated from ‘Run’ battery data during charging process			
Notes	[3] Energy available from ‘Run’ battery for an external load when battery swapping enabled to maintain battery charge level. Calculated as ‘Energy Returned to Batt.’ (1) - ‘Energy Supplied to Gen.’ (2)										
Notes	[4] Time taken to replace discharged energy to ‘Receiving’ battery. Calculated from the proportion of the time taken to reach the final charging voltage compared to $V_{(pk)}$ and equals ((Run time + (Run time x ($V_{(pk)}$ - V_{final}) / (V_{final} - V_{start}))) / 60										
Notes	[5] Available power for an external load over the full recharge time. Calculated as Energy Available (3) / Time Taken (4)										

Table 6: Summary Table

provides a good indication of what the live power tests will deliver when they are completed.

Such tests will require the use of the battery swapper so that the energy delivered to the circuit and the external load by the run battery can be replaced when it becomes the receiving battery, a cycle repeating approximately every 15-30mins. The maximum load that can be supported will be that for which the both batteries never drop below a threshold voltage, indicating that energy harvesting is occurring to maintain their energy state.

Table 6 above brings together the various calculated values, including theoretical calculations of the power available for an external load over the time taken for the battery to reach full charge. These predictions have yet to be confirmed by full load tests and will be the topic of a future report.

Error (Uncertainty) Analysis:

No readings are complete without an analysis of the uncertainties involved in the measurement process and there were some assumptions made, such as the linearity of the charging profile, that are consistent throughout the testing process and which will be integrated into the results of the forthcoming load tests.

From statistics theory, and using a simplified method of error propagation (cf partial derivatives method), the total relative uncertainty of a value derived from the multiplication of its component values i.e. $E_{(Supplied)} = V_{(av)} . I_{(av)} . t_{(Run)}$ J, is comprised of the sum of the individual relative uncertainties:

Rel. $U_{Es} = \delta_{Es} = \delta_V + \delta_I + \delta_t$

Also $\delta_{Es} = \Delta_{Es} / E_{(Supplied)} \therefore \Delta_{Es} = \delta_{Es} \times E_{(Supplied)} = (\delta_V + \delta_I + \delta_t) \times E_{(Supplied)}$

Although extrapolation has been used to determine the final value of the energy supplied, and a value of Δ_{Es} of 100J (0.1kJ) could have been used based on the uncertainty in reading the X axis value, since the computational value has been calculated at 207J, this larger value has been used in the calculation of the uncertainty.

δ_{Es} has been derived from the equipment specifications and calculated to be 2.14E-02.

$\therefore \Delta_{Es} =$ 2.14E-02 x 9,700 = 207J

For the energy discharged by the CBA, and subsequently returned to the receiving battery, the absolute uncertainty Δ_{Er} = 360J based on the device specifications and a more conservative value of the uncertainty in the measured energy dissipated of 0.1Wh (360J).

$E_{(Received)} = E_{(Discharged)}$ (direct measurement) J

Similarly the Rel. $U_{Er} = \delta_{Er} = \Delta_{Er} / E_{(Received)} = 360 / 63{,}970 = 5.63E\text{-}03$

For the CoP, the total uncertainty of a value derived from the division of its component values i.e. CoP = $E_{(Received)} / E_{(Supplied)}$, is calculated by adding the component relative uncertainties such that:

$$\Delta_{CoP} / CoP = \delta_{CoP} = (\delta_{Er} + \delta_{Es}) \quad \therefore \quad \Delta_{CoP} = (\delta_{Er} + \delta_{Es}) \times CoP$$

$$\therefore \Delta_{CoP} = (5.63E\text{-}03 + 2.14E\text{-}02) \times 6.59 = (2.70E\text{-}02) \times 6.59 = 0.18$$

The figures for the calculated uncertainties are shown in Tables 5 and 6 along with the values of CoP. So specifically for Test 4, the value of CoP is 6.58 ± 0.18 and so the actual value lies in the range 6.40 - 6.76.

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[What follows are some ideas regarding how I would go about gathering the load test data and how I might calculate the uncertainty and establish some confidence level in the results.]

Each test run to measure power will aim to find out if both batteries retain the voltages that they started with after completion of a series of swap cycles. After a swap interval the batteries swap over their roles, as either run or receiving battery, and two swap intervals make up a swap cycle so that after that time the batteries are back in the same roles they started with.

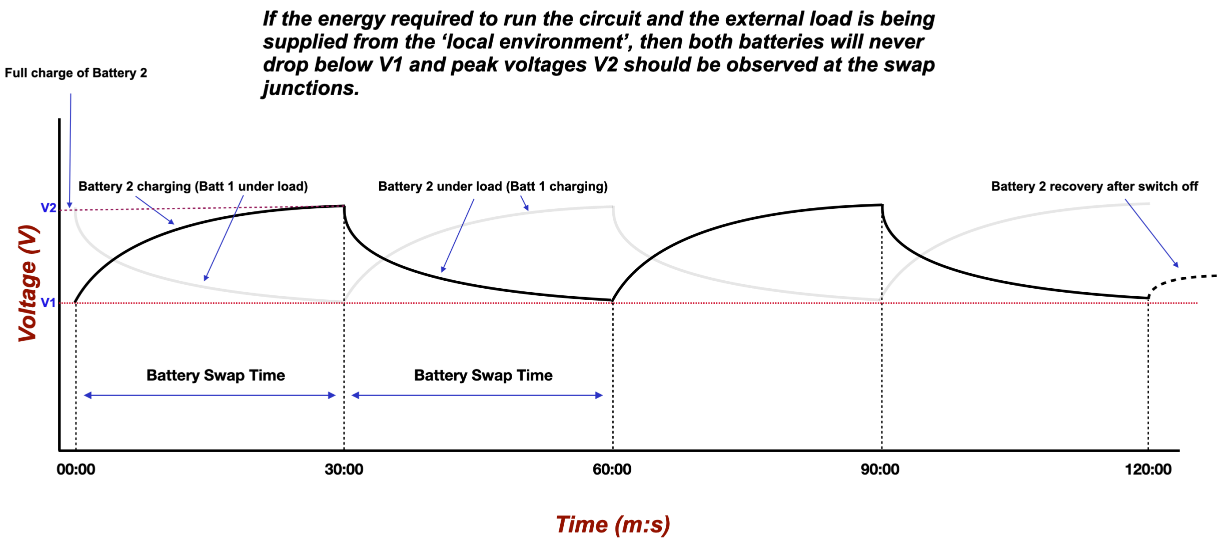

Fig 5: Swap cycles used in power tests

This process is illustrated in Fig 5 where the graph shows just four swap intervals before switching off and the batteries then stabilised so that their voltages can be read.

To clarify what this graph presents, the measurement process starts with Battery 2 as the battery being pulse charged (receiving) and Battery 1 as the supply battery. Battery 2 will start its charging from a condition of partial discharge at a voltage V1, while battery 1 will be supplying current from a state of full, or near full, charge at a voltage V2.

After the generator has been running for 30mins, the swapper system reverses the battery roles and battery 2 now starts to supply the circuit and the external load and battery 1 starts being pulse charged.

The battery swapping continues for a total of four times for each of the test runs, such that two full swap cycles are completed. The generator is switched off after 120 mins, the batteries allowed to stabilise and voltage readings taken.

The aim of the test using this method is to find out the maximum power drain, through the external load, that can be sustained such that both batteries never drop below the minimum voltage V1 and, at the point of maximum charging, that they reach their peak voltage V2 at their respective times in the cycles. The sequence of energy flow with battery swapping is illustrated in Fig 6.

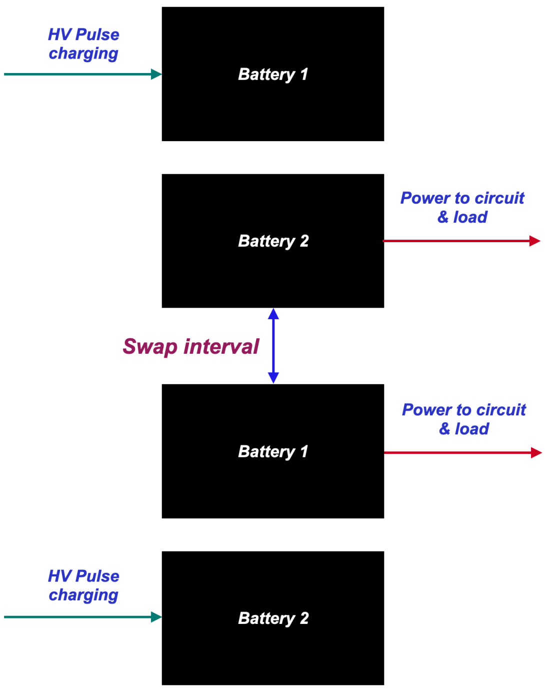

Fig 6: Energy flow with battery swapping

During an actual test run, the ‘charge monitor’ function of the CBA will plot voltage against time and so the general shape of the above illustration will be recorded as used in the previous CoP tests. From the resulting graph the values of V1 and V2 can be seen. In addition the values can also be read after switch off and stabilisation if the cycle is stopped at the point of the fourth and final switchover.

Given that one will not know if the battery voltage will drop for a given power output, then the power demand will need to be incremented with each test run until the battery voltages just start to drop. What this then means in practice is that the demand on the run battery is just a bit more than the pulse charging process can replenish when it becomes the receiving battery.

The readings that will result from this process will likely take the form of a spreadsheet table as shown in Table 7. This shows made-up but realistic test data for six test runs.

Data - Exp 7: Load Tests

Blue - data input *Red - Auto Fill/Calculations*

Battery IDs: & Capacity: Chemistry:

Test No.	PRF (Hz)	Load (W)	Load I (A)	Swap Interval (min)	Swaps	V1 [1]	V2 [2]	V1 End	dV1 [5]	V3 [3]	V4 [4]	V3 End	dV2 [6]	CBA Test ID	Screengrab File
1	180	50.0	4.02	12.00	4	12.48	12.85	12.48	0.00	12.83	12.45	12.83	0.00	071222-Charge Monitor 1.bt2	071222-Charge Monitor 1.png
2	180	60.0	4.82	12.00	4	12.48	12.85	12.48	0.00	12.83	12.45	12.83	0.00	071222-Charge Monitor 2.bt2	071222-Charge Monitor 2.png
3	180	70.0	5.62	12.00	4	12.48	12.85	12.48	0.00	12.83	12.45	12.83	0.00	081222-Charge Monitor 1.bt2	081222-Charge Monitor 1.png
4	180	80.0	6.43	12.00	4	12.48	12.85	12.48	0.00	12.83	12.45	12.83	0.00	081222-Charge Monitor 2.bt2	081222-Charge Monitor 2.png
5	180	90.0	7.23	12.00	4	12.48	12.85	12.48	0.00	12.83	12.45	12.83	0.00	091222-Charge Monitor 1.bt2	091222-Charge Monitor 1.png
6	180	95.0	7.63	12.00	4	12.48	12.83	12.46	-0.02	12.83	12.43	12.81	-0.02	091222-Charge Monitor 2.bt2	091222-Charge Monitor 2.png
7															
8															

Notes: [1] V1 is the voltage of Battery 2 (charging) at the start of test and is the reference voltage for any change at the end of the test. [2] V2 is the peak voltage of Battery 2 at the end of a swap interval

Notes: [3] V3 is the voltage of Battery 1 (supply) at the start of the test and is the reference voltage for any change at the end of the test. [4] V4 is the voltage of Battery 1 at the end of a swap interval

Notes: [5] This value should be ≥ 0 until the power demand exceeds that available from the energy influx [6] The same as for note 5.

Table 7: Sample Load Test Data

Given these test arrangements, a few questions arise with regard to obtaining sufficient data to enable me to derive meaningful results and to calculate relevant uncertainties.

These are:

1. How many test runs, using the same parameters, are required to give a statistically significant reading of the load value that starts to drop the battery voltage?

2. How do I determine the uncertainty for the above value of power, the value that does not start to drop the battery voltages, i.e. that dV1 and dV2 in the table are greater than or equal to zero? Is the method shown below, which is essentially the same as used in the CoP test, appropriate?

3. Are there are statistical values that I should derive that are important in giving a confidence level to the data?

Available Power (Δ_P)

For the available external power, the total relative uncertainty of a value derived from the multiplication of its component values i.e. $P_{(available)} = E_{(available)}$ / time is comprised of the sum of the individual relative uncertainties:

Rel. $U_E = \delta_E = \Delta_E / E = 0.1/54.3 = 1.8E\text{-}03$

Rel. $U_t = \delta_t = \Delta_t / t = 0.1/17 = 5.9E\text{-}03$

Rel. $U_P = \delta_P = \delta_E + \delta_t = 1.8E\text{-}03 + 5.9E\text{-}03 = 7.7E\text{-}03$

Also $\delta_P = \Delta_P / P_{(Available)} \therefore \Delta_P = \delta_P \times P_{(Available)} = 7.7E\text{-}03 \times 53.2W = 0.41W$

Julian Perry
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