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Article

Standardization Work for BEV and HEV Applications: Critical Appraisal of Recent Traction Battery Documents

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Abstract: The increased activity in the field of Battery Electric Vehicles (BEVs) and Hybrid Electric Vehicles (HEVs) have led to an increase in standardization work, performed by both world-wide organizations like the IEC or the ISO, as by regional and national bodies such as CEN, CENELEC, SAE or JEVA. The issues of these standards cover several topics: safety, performance and operational/dimension issues. This paper reports a brief overview of current standardization activities of lithium batteries based on IEC 62660-1/2 and ISO 12405-1/2. Furthermore, in this paper, a series of innovative test procedures for lithium-ion batteries are presented. Thanks to these tests, the general characteristics of a battery such as charge and discharge capabilities, power performances and life cycle can be determined. Then, a new approach for extracting the life cycle of a battery in function of depth of discharge has been developed.

Keywords: lithium batteries; energy density; power density; performance tests; HPPC-test

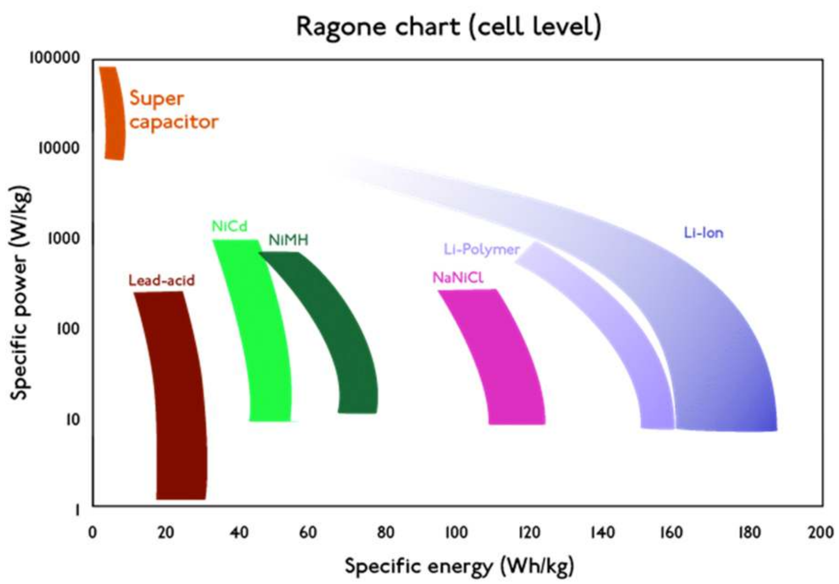
1. Introduction

As the global economy begins to strain under the pressure of rising petroleum prices and environmental concerns, research has spurred the development of various types of Hybrid Electric Vehicles (HEVs), Battery Electric Vehicles (BEV) and Plug-in Electric Vehicles (PHEV). HEVs and PHEVs usually require more than one energy source to provide more efficient propulsion. The energy sources should satisfy the following basic operational requirements [1]:

- Sufficient power capabilities, so that the necessary power required for propulsion can be supplied to the motor in any reasonable driving condition;
- Quick charging time, in order to increase vehicle availability;
- Sufficient lifetime, both in terms of calendar life and number of charge/discharge cycles;
- Cost.

Unfortunately, there is no single available battery on the market that satisfies all the criteria as stated above. One of the more serious problems with these vehicles is the present dependence on very expensive batteries such as nickel metal hydride (NiMH). At present, lead-acid actually is the only economically attractive battery, but it is ill-suited for HEV’s because of the frequent cycling and the fact that the state of charge (SoC) must be held below about 70% to accept regenerative energy [2–5]. The Ragone plot in Figure 1 shows that lithium batteries have the best performance in terms of energy density and power density. It should be noted however that the plot area represents several battery designs optimized for either power or energy.

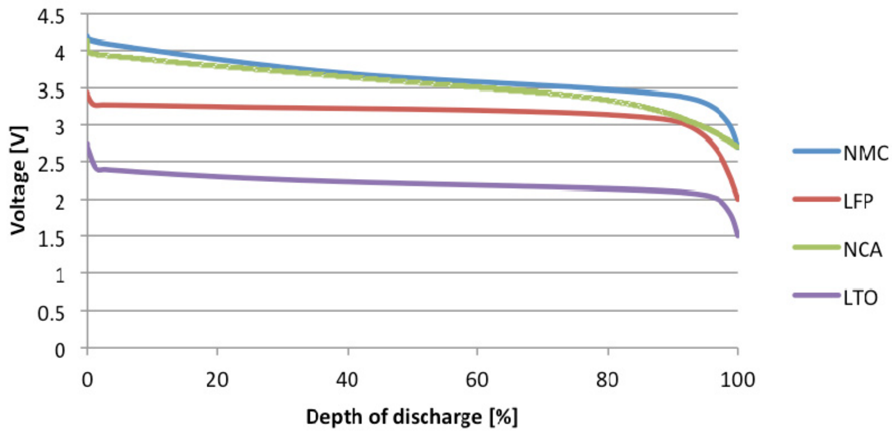
Figure 1. Rangone plot [3].



Lithium-ion batteries have shown their suitability in portable applications because of their high specific energy, lack of memory effect, and slow self-discharge when not in use [6]. In addition to consumer electronics, lithium-ion batteries are increasingly used in defence, automotive, and aerospace applications due to their superiority over any battery technology in terms of high energy density and high power capabilities. Several types of lithium technologies can be found on the market, such as

Lithium Iron Phosphate (LFP), Lithium Nickel Cobalt Aluminum (NCA), Lithium Nickel Manganese Cobalt (NMC), Lithium Titante Oxide, *etc.* (Figure 2) [7,8]. All these batteries differ in capacity, energy, performances and potential safety hazards. In order to investigate the applicability of lithium-ion batteries, especially power and energy capabilities, in BEV and HEV applications; they shall to be subjected to specific test procedures.

Figure 2. Voltage duration of various lithium-ion chemistries.



In the literature, one can find a number of papers regarding characterization of batteries for modeling and performances purposes. In [9–19] some test methodologies are introduced in order to obtain the general characteristics of lithium-ion batteries. However, the used test procedures are mainly based on constant current rates during discharge phase. These profiles are intended to investigate the discharge capabilities and to study the thermal behaviour and hysteresis curves of the examined batteries. In [20] Andre *et al.* used the sinusoidal load profiles for characterization of high power lithium-ion batteries by using electrochemical impedance spectroscopy. However, the current level of such measurement devices is limited to few amperes. In [21] Lee *et al.* have applied real load profiles for the evaluation of battery behaviour. In addition, in [22–25], asymmetrical and symmetrical load profiles have been implemented for emulating the battery voltage response during discharge phase. However, these mentioned profiles are only useful to investigate a well-defined problem. In order to be able to investigate and to compare the battery performances at different conditions, there is a need to use test procedures where all relevant battery performance characteristics can be derived. Moreover, these tests should be able for modeling issues, where emphasis is on extracting the model parameters. In the standard documents ISO 12405-1, ISO 12405-2 and IEC 62660-1/2 [26–29], some general test procedures in order to extract the power and energy densities of the batteries are defined. However, each test method is only suited to get one-performance characteristics. The characterization of all battery parameters is by this way time consuming and cumbersome, and is almost all at constant currents.

In this paper, the latest standardization works in the fields of lithium-ion batteries for BEV and HEV applications are extensively discussed and evaluated. The defined test procedures in the standards IEC 62660-1/2 and ISO 12405-1/2 have at first been analyzed based on experimental implementation of the test procedures in a battery test equipment. Then the tests have been modified in order to make them efficient and suitable for implementation.

Furthermore, this paper proposes a new approach for determining the battery life cycle in function of depth of discharge.

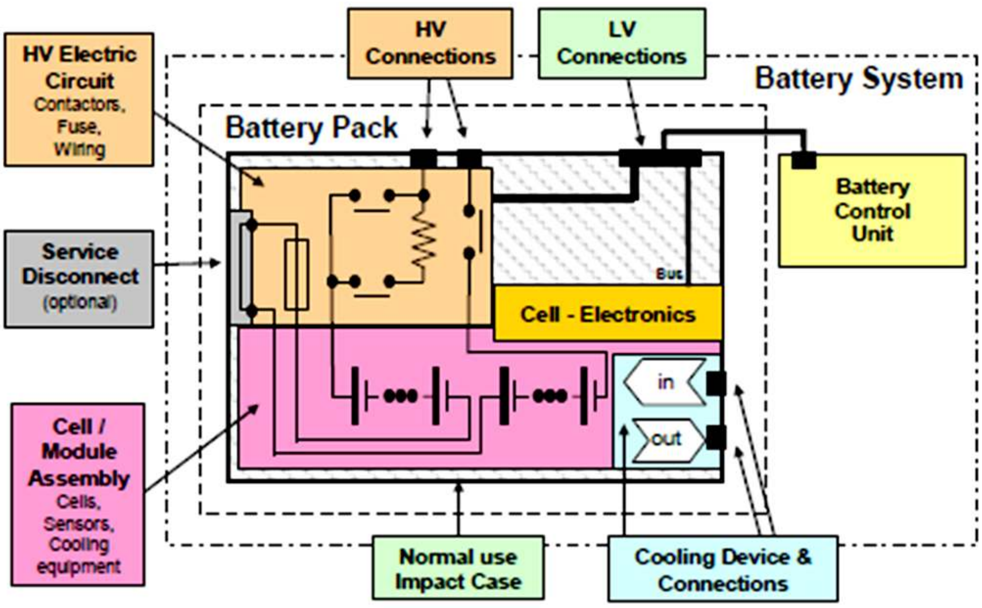
2. Standardization Work

In the literature, one can find a series of test procedures in order to investigate the performances of batteries. Classical standards such as the IEC 60254 for lead batteries [4] typically use constant current discharge cycles. Dynamic discharge profiles have been introduced in the IEC 61982-2 [30], typical for nickel-based batteries in battery electric vehicles. However, existing battery standards are not appropriate for the emerging technologies such as lithium-ion batteries.

New work is being performed on lithium-ion batteries, both by ISO TC22 SC21 and IEC TC21/SC21A/TC69, with several documents being published (ISO 12405-1/2, IEC 62660-1/2, [6–9]) describing specific test procedures to determine their applicability in HEV and BEV applications. The issues of these standards cover several topics: performance, reliability and safety. This paper handles the performance issues and life cycle test methods. Other issues (no-load capacity, capacity loss at storage, cranking power at low & high temperature) as well as safety issues fall outside of the scope of this paper.

The unusual fact that both IEC and ISO are working on similar documents is a typical illustration of the awkward split of the electrically propelled vehicle standardization between vehicle-oriented committees (ISO TC22 SC21) and electrotechnical committees (IEC TC21) which each have their own standardization cultures [10]. In this case an agreement has been reached to have the ISO document consider the battery system from a vehicle point of view, encompassing both the battery cells and their auxiliary equipment such as cell electronics, high voltage circuit and over current shut-off device including electrical interconnections, interfaces for cooling, high voltage, auxiliary low voltage and communication as presented in Figure 3.

Figure 3. Battery pack system [27].



3. Energy and Power Performances for BEV and HEV Applications

3.1. Pre-Conditioning Test

Table 1. Overview of the defined test in the standard ISO/CD 12405-1/2 and IEC 62660-1.

Test item	Test	Condition	Pack/System ISO/CD 12405-1/2	Extended	Cell IEC 62660-1	Extended
Pre-conditioning	Cycling	Temperature	25 °C		25 °C	
		Charge	standard charge		Standard Charge	
		Discharge	2C		0.2C	$2I_t$
		# Cycles	5		5	
Energy and capacity	CC discharge	Temperature	−18 °C, 0 °C, 25 °C, 40 °C		−20 °C, 0 °C, 25 °C, 45 °C	
		Charge	standard charge	# I_t-rates until max charge I_t-rate (as $1/3I_t$, $1I_t$, $2I_t$, ...)	standard charge	# I_t-rates until max charge I_t-rate (as $1/3I_t$, $1I_t$, $2I_t$, ...)
		Discharge	1C, 10C, 20C, I_{max}	$1/3I_t$, $2I_t$, $5I_t$	1C, 10C, 20C, I_{max}	$1/3I_t$, $2I_t$, $5I_t$
		# cycles	2		2	
Power and resistance	Pulse charge/ discharge	Temperature	−18 °C, 0 °C, 25 °C, 40 °C		−20 °C, 0 °C, 25 °C, 45 °C	40 °C instead of 45 °C
		Discharge	I_{max}, dis	$1/3I_t$, $2I_t$, $5I_t$, $10I_t$	0.2C, 1C, 5C, 10C	$1/3I_t$, $2I_t$, I_{max}
		Duration	0.1 s, 2 s, 10 s, 18 s		10 s	
		Charge	$0.75*I_{max}$, dis	$1/3I_t$, $2I_t$, $5I_t$, $10I_t$, I_{max}	1/3C, 1C, 5C, 10C	$2I_t$, I_{max}
		Duration	0.1 s, 2 s, 10 s		10s	
		SoC	80%, 65%, 50%, 35%, 20%		50%	80%, 65%, 35%, 20%
Energy efficiency	Pulse charge/ discharge	Temperature	0 °C, 25 °C, 40 °C	−18 °C	−20 °C, 0 °C, 25 °C, 45 °C	40 °C instead of 45 °C
		Discharge	See sequence in Table 4	$1/3I_t$, $1I_t$, $2I_t$, $5I_t$, $10I_t$, I_{max}	1/3C, 1C, 5C, 10C	$2I_t$, I_{max}
		Duration		10s	10s	
		Charge	See sequence in Table 4	$1/3I_t$, $1I_t$, $2I_t$, $5I_t$, $10I_t$, I_{max}	1/3C, 1C, 5C, 10C	$2I_t$, I_{max}
		Duration		10 s	10 s	
		SoC	65%, 50%, 35%	80%, 20%	50%	80%, 65%, 35%, 20%

As one can see in Table 1, the specifications of each test procedure according to ISO 12405 and IEC 62660-1 are presented. As defined in Table 1, before starting the real testing sequence, the battery pack (or a cell) should be subjected to some pre-conditioning cycles (five cycles), in order to be sure that an adequate stabilization of the battery pack (or a cell) is reached. The standard considers a battery pack (or a cell) as "preconditioned" when the discharged capacity during two consecutive discharges does not change by a value greater than 3% of the rated capacity. The discharge and charge should to be performed according to the manufacturer's specifications [26,27]. However, the term rated capacity should be interpreted very carefully. In Table 2, we observe that the discharge capacity is about 45 Ah instead of 40 Ah as specified by the manufacturer. Hereby, the rated capacity should be a measured value (e.g., at 2C) when the cell or battery is pre-conditioned.

Table 2. Pre-conditioning test results LFP batteries 40 Ah.

	Cycle 1 (Ah)	Cycle 2 (Ah)	Cycle 3 (Ah)	Cycle 4 (Ah)	Cycle 5 (Ah)
Cell 1	46.83	46.86	46.78	46.69	46.59
Cell 2	45.54	45.50	45.36	45.26	45.15
Cell 3	46.24	46.31	45.25	46.19	46.11

3.2. Energy Capabilities

As mentioned in Table 1, the second performance test is the energy and capacity test. According to this test, different batteries can be compared in terms of discharge capacity at different discharge rates, which is essential in battery electric vehicle applications. This test measures battery (or a cell) capacity in Ah at constant current discharge rates 1C, 10C, 20C and I_{max}. Discharge is terminated on a manufacturer specified discharge voltage limit. However, the numbers of batteries, which are allowed at 10C or 20C are very limited. The discharge current of the most available high energy batteries (or cells) on the market are between 0 and 5C for BEV and up to 15C for HEV applications. In order to take the specifications of these batteries (or cells) in account, the proposed test procedure should be extended to 2C and 5C. It should be noted that the standards specify the current in function of the rated capacity (C) of the battery pack (or a cell). This is a common expression, but a dimensional error taking into account, totally in contradiction with the unit of the current: ampere. In order to solve this, a «reference current» as specified in the standard IEC 61434 can be used [31]:

$$I_t = \frac{C}{1h} \tag{1}$$

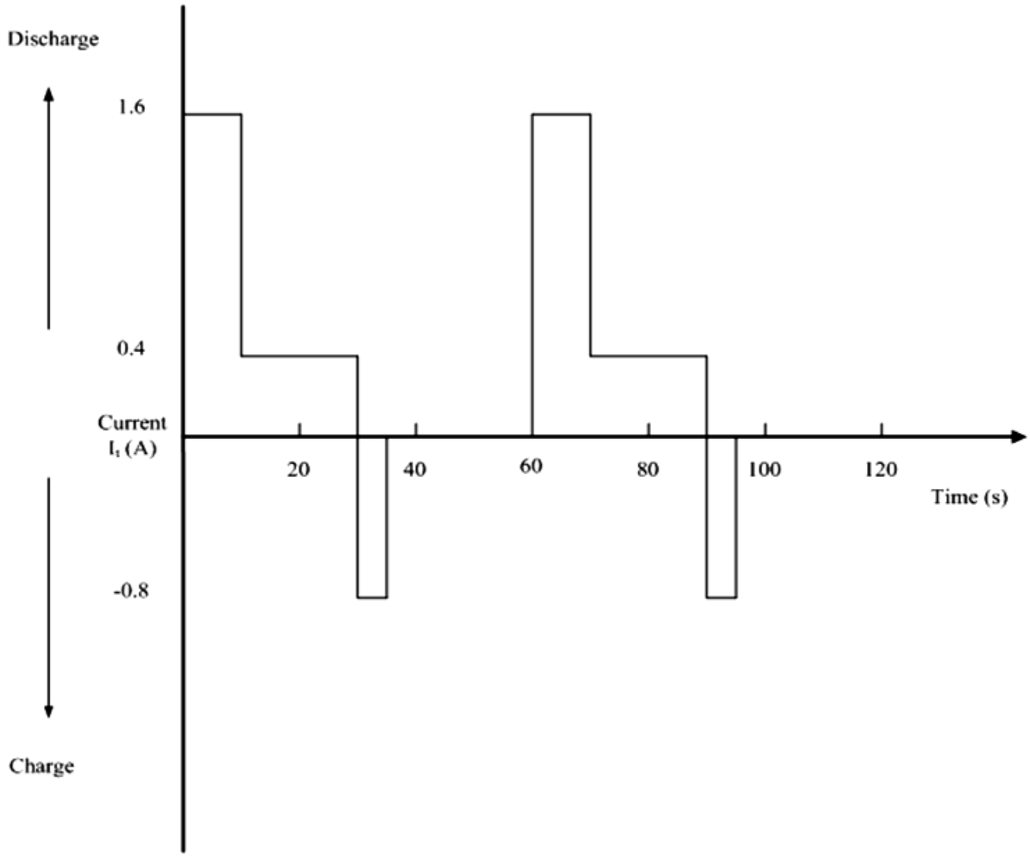
The current I_t represents the discharge current in amperes during one hour discharge and C is the measured capacity of a battery pack (or a cell). As presented in Table 1, the test procedure of the capacity and energy test shows different temperatures. In order to compare the performances of a battery pack with the performances of a cell at different temperatures, the temperatures in both cases should be equal and not different as specified in Table 1.

Based on the capacity test, one can calculate the energy density. However, discharging a battery a constant current does not reflect the battery behaviour in BEVs and PHEVs. The discharge performance test presented in Figure 4 is more appropriate. The energy density can be obtained by using the following equation:

$$E = C_{dis} \cdot \frac{V_{aver}}{m} \tag{2}$$

where E is the energy density (Wh/kg) and C_{dis} corresponds to the discharge capacity. V_{aver} represents the average voltage during discharging phase and m is the mass (kg).

Figure 4. Dynamic Discharge Performance Test [30].



Furthermore, the capacity test does not contain any test sequences regarding charge rate capabilities of batteries. Van den Bossche *et al.* [32] underlined the essential of this aspect due to emerging advance of various charge systems for BEVs and PHEVs. In the framework of this paper, a novel test procedure has been developed (see Figure 5), where the charge and discharge capabilities of a battery cell or pack can be mapped out. In Figure 5, we see that the test presents consecutive charge and discharge phases at different current rates. By this way, the well known Peukert phenomenon can be derived during discharge and the efficiency map at various charge current rates (Figure 6).

The charge efficiency in Figure 6 represents the ratio of stored capacity in Ah at a certain current rate and capacity in Ah at $1I_t$ as presented by Equation (3):

$$Eff_{\text{charge}} = \frac{C_{xIt}}{C_{1It}} \quad (3)$$

The proposed test allows us to estimate the state of charge (SoC) of a battery based on the ampere-hour counting as presented below. The Equation (4) contains all key parameters, which influence the SoC estimation:

$$SoC = 1 - \begin{cases} \dfrac{I_{bat}.T_s}{C.3600}\left(\dfrac{I_{bat}}{I}\right)^{n(LC,t^\circ)-1} & if\ I > 0 \\ -\left[Eff\left(I_{bat}, t^\circ, LC\right).\int I_{bat}.dt\right] & if\ I < 0 \end{cases} \quad (4)$$

with I_{bat} represents the applied battery current in (A), T_s is the step time (s), *n*, *LC*, *t*° are the Peukert constant, life cycle and temperature, respectively. The notation I corresponds to the nominal current, while E_{ff} is the Coulomb charge efficiency.

Figure 5. Newly developed energy and capacity test at different current rates.

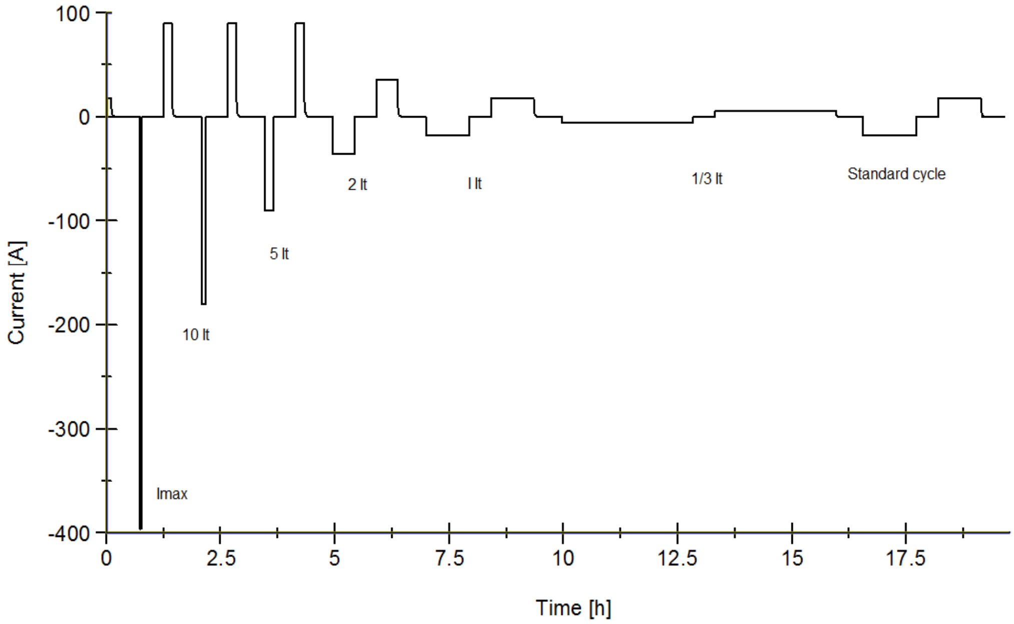


Figure 6. Charge efficiency during CC phase at cell level.

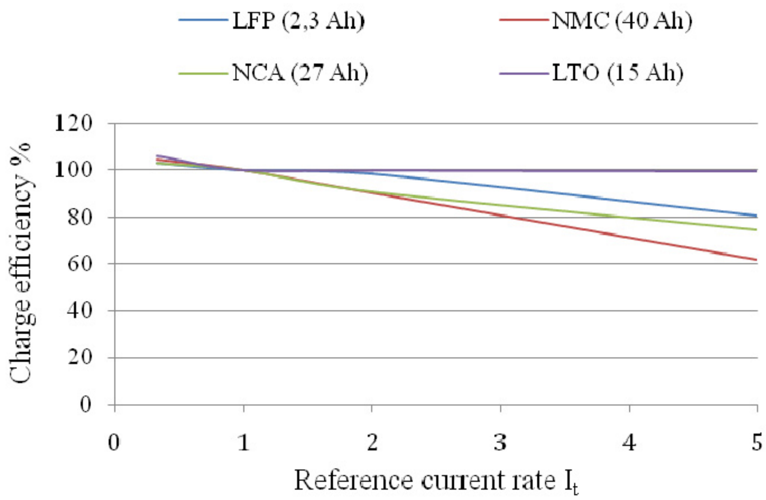
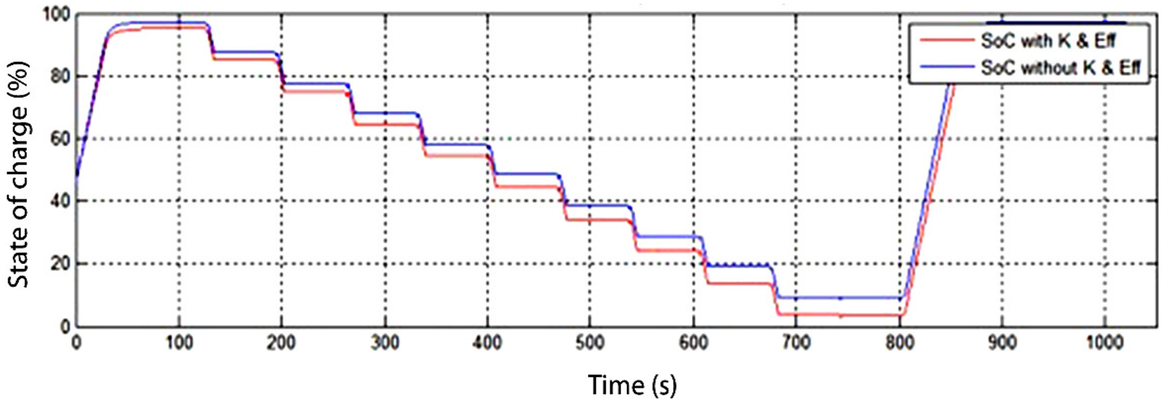


Figure 7 shows the impact of the Peukert number and the efficiency on the state of charge estimation. It is clear that during real battery operation the battery significantly suffers because of the high current rates.

Figure 7. State of charge estimation including Peukert and efficiency.



Further, the standard ISO 12405-1 specify that the test procedure should be performed at least two times. Before starting the real test sequence at different temperatures (see Table 1), an acclimatization step has to be carried out [26,27]. This step will be terminated until a temperature stabilization of ±2 K is reached. From the experience of the author, this step takes around 24 h. Due to the fact that an acclimatization process should happen before starting the energy and capacity test at the temperatures (e.g., −18 °C, 0 °C and 40 °C), this test procedure becomes time consuming. However, the time duration of this test can be reduced by performing the energy and capacity test separately at the defined temperatures without performing the acclimatization step between the other temperatures.

3.3. Power Capabilities

The third performance test in Table 1 is the hybrid pulse power characterization test, also known as the HPPC test [33]. This test investigates the power capabilities of a battery pack (or a cell) under operating conditions at different temperatures, pulse widths and state of charge (SoC). The HPPC test based on the defined test sequence provides the parameters of several battery models such as Thevenin, FreedomCar and second order FreedomCar, as can be seen in Figure 8.

The objective of this profile is to demonstrate the discharge pulse power (0.1 s, 2 s, 10 s and 18 s) and regenerative charge pulse power (0.1 s, 2 s, and 10 s) capabilities at various SoC and temperatures. The normal test protocol uses the manufacturer's maximum rated pulse discharge current with an upper limitation of 400 A. The current of the regenerative charge pulse shall be kept constant and is calculated at 75% of the discharge pulse current [26,27]. It can be clearly recognized that this test procedure in the present form displays some drawbacks such as acclimatization processes, which are time consuming, as seen in the previous paragraph. Furthermore, the test procedure specifies different pulse widths, which are beyond the allowed performance envelope for most battery packs or cells. Due to the fact that the charge and discharge pulses are not equal, the efficiency of the battery pack or cell cannot be determined since it should be calculated by performing similar tests at equal pulse rates. Finally, the proposals have to be adjusted in the sense that the regenerative charge pulse should not exceed the manufacturer's maximum pulse regenerative voltage. Based on these drawbacks as discussed above and in the previous paragraph, a new test procedure has been developed at the Vrije Universiteit Brussel and Vito Research Institute, which is called the Extended Pulse Power

Characterization Test (Extended HPPC). As one can see in Figure 9, the Extended HPPC test has been modified by multiple equal pulse rates. In the modified form the test can be performed at different equal charge and discharge pulses if permitted by the manufacturer. Due to these modifications, the power capabilities can be calculated at different state of charge values and pulse rates ($1/3I_t$, $1I_t$, $2I_t$, $5I_t$, $10I_t$, $20I_t$ and I_{max}). Further the energy efficiency test as listed in Table 1 can be avoided due to the fact that the pulse rates are equal. The new proposed test procedure is developed only for 10 s pulse because the most batteries or cells are specified at 10 s in analogy with Draft IEC 62660-1. According to the performed modifications, all relevant battery model characteristics can be mapped out.

Figure 8. Second order battery model.

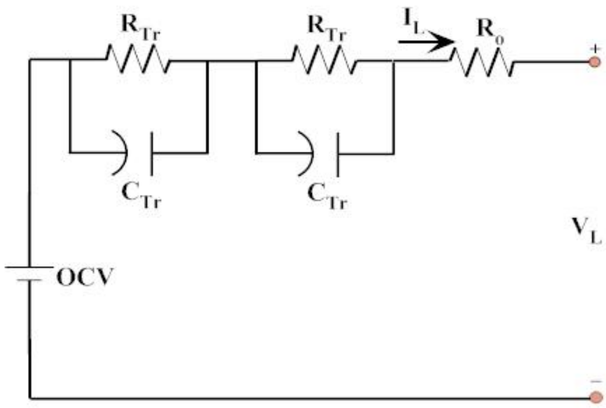
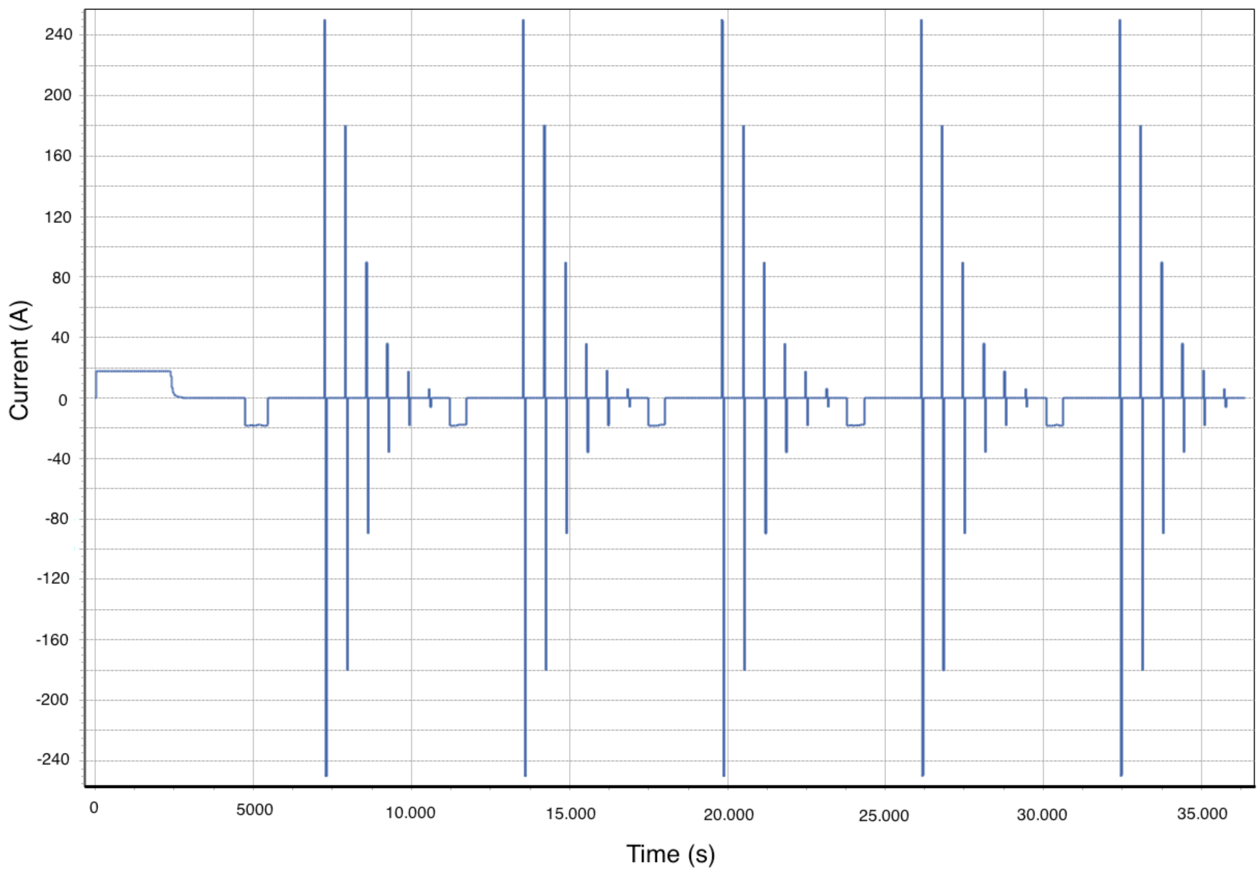


Figure 9. Extended Hybrid Pulse Power Characterization Test.



It should be noted that the rest period between two consecutive pulses is 10 min instead of 30 min as specified in the ISO 12405-1/2 standards [26,27]. This modification has been down in order to shorten the time schedule of the test procedure. However, this modification does not have an impact on the accuracy of the estimated battery model parameters, as presented in Table 3.

Table 3. Comparison of the simulation results for both scenarios.

15 min	**Break**					
OCV	OCV'	Ri	Rp1	τ1	Rp2	τ2
3.303	0.017	0.010	0.004	3.109	0.005	44.99
10 min	**Break**					
OCV	OCV'	Ri	Rp1	τ1	Rp2	τ2
3.300	0.018	0.011	0.003	3.102	0.005	44.89

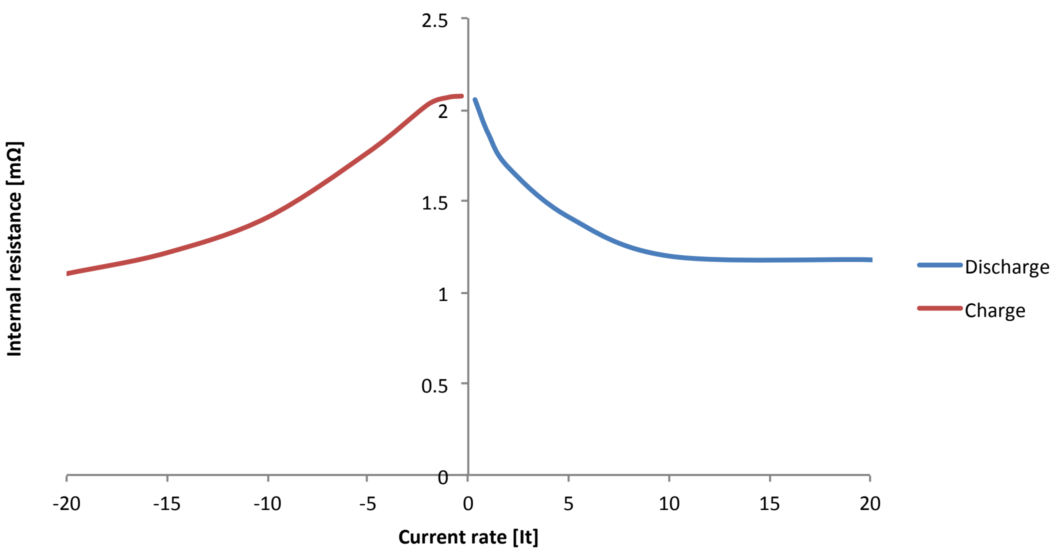
This test is also able to figure out the well-known Butler-Volmer phenomenon. As we can see in Figure 10, the internal resistance decreases the more the current rate increase. However, this result is slightly confusing with the consideration that the energy efficiency decreases at higher current rates. This relationship has been described by Butler-Volmer [34]. General expression of their equation is presented in Equation (5):

$$I = I_o \cdot \left\{ e^{\left(\frac{aF}{RT}\cdot(V-V_o)\right)} - e^{\left(\frac{(1-a)F}{RT}\cdot(V-V_o)\right)} \right\} \quad (3)$$

where I_o is the current density, α presents the transfer coefficient, R is the universal gas constant and F is the Faraday constant. While T is the temperature, V and V_o represent the electrode and equilibrium voltages.

As one can see, the equation gives the relationship between the current and the voltage. The voltage can be considered as logarithmically dependent on the current. Hence, the evolution of the battery internal resistance is increasing in function of decreased C-rates. Still, the energy efficiency decreases with increasing current due to quadratic dependence of the loss on the current: RI^2.

Figure 10. Butler-Volmer phenomenon at lithium-ion cell level.



3.4. Energy Efficiency

The standard IEC 62660-1 at the cell level specify that the energy efficiency test should be carried out by applying equal charge and discharge pulses [28]. However, the ISO 12404-1/2 system-level standards define the energy efficiency test by using the test sequence, as presented by Table 4. In order to investigate the difference between both methods, two tests have been performed at room temperature (RT) with I_{max} equal to $5I_t$ (for a 2.3 Ah LFP battery cell). The experimental results reveal that the energy efficiency according to the IEC 62660-1 is about 89%, while the efficiency based on the other method is 91%. The higher result of the latter one is due to the lower currents that are applied, which have a positive impact on the battery behaviour and efficiency.

Table 4. Test sequence energy efficiency according to ISO/CD 12405-1/2 [28].

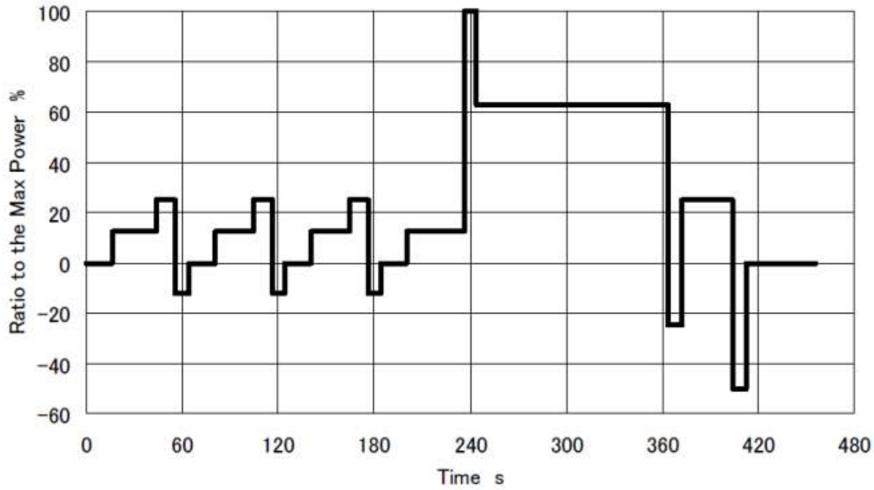
Time Increment (s)	Time Cumulative (s)	Current
0	0	0
12	12	$20I_t$ or I_{max}
40	52	0
16	68	$-15I_t$ or I_{max}
40	108	0

4. Life Cycle Tests

4.1. High Energy

The standard IEC 62660-1 also contains a part about life cycle tests in function of the desired application (battery electric or hybrid electric vehicle). Although the battery electric micro-cycle contains of consecutive charge and discharge pulses, its overall characteristic is charge depleting as can be seen in Figure 11 [28]. The standard IEC 62660-1 specifies that the cell should be subjected to the micro-cycle (Figure 11) until the depth of discharge capacity is 80%, after which the cell will be fully charged. This process of charging and discharging will continue until the cell capacity at $1I_t$ has reached 80% of the initial capacity. The standard specifies that the test should be performed at 45 °C in order to accelerate the ageing mechanism of the test. However, the numbers of commercial lithium-ion batteries that can operate at this charge temperature are very limited [7]. For the most batteries, the charge temperature range is up to 40°C. Cycling the cells (or battery) at higher temperature can lead to damage the battery. However, the results which can be obtained from the mentioned test are not relevant to compare the batteries to each other due to the fact that the life cycle of the cells as specified by the manufacturer are derived at room temperature. The standard purposes to convert the obtained value (45 °C) into a calculated value at room temperature by using the Arrhenius law. However, the Arrhenius law can be used only in the cases when the system is exponential. Due to the fact that the Li-Ion cells are complex rather than exponential, the obtained value according to the standard will not represent a realistic value.

Figure 11. IEC micro-cycle for battery electric vehicle (profileB) [27].



Possible solutions to speed up the ageing mechanisms are the increase of the current rate or the extension of the depth of discharge window. In order to reduce the time duration of the life cycle test, a novel test method has been developed by Punch Powertrain and investigated & optimized at Vrije Universiteit Brussel where the life cycle of a battery can be obtained in function of depth of discharge (DoD). In real applications the depth of discharge has a key impact on the life cycle of a battery (or a cell). In this method, the cells are connected as illustrated in Figure 12. The four connected cells in series will be discharged deeper and undergo higher stress than the other cells. Through this way of connection, one can derive the life cycle in function of depth of discharge DoD. Finally, this test provides also the voltage unbalance in the case of the connected cells in series and current unbalance of the connected stacks in parallel in function of DoD and life cycle. This approach has been examined at laboratory level. The experimental results indicate that the battery cells at each cycle should be balanced. Especially the first four cells in series undergo big differences at high current rates as is presented in Figure 13 and Figure 14. Hereby, the discharge capacity during one cycle is limited to 6.44 Ah instead of 9 Ah, which is the nominal capacity. However, the proposed life cycle approach is powerful when a balancing system will be used in real time conditions.

Figure 12. Novel life cycle topology.

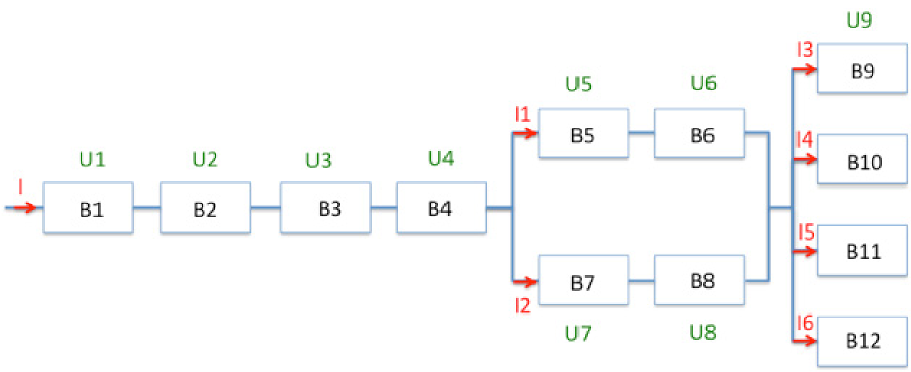


Figure 13. Experimental results of the Punch topology.

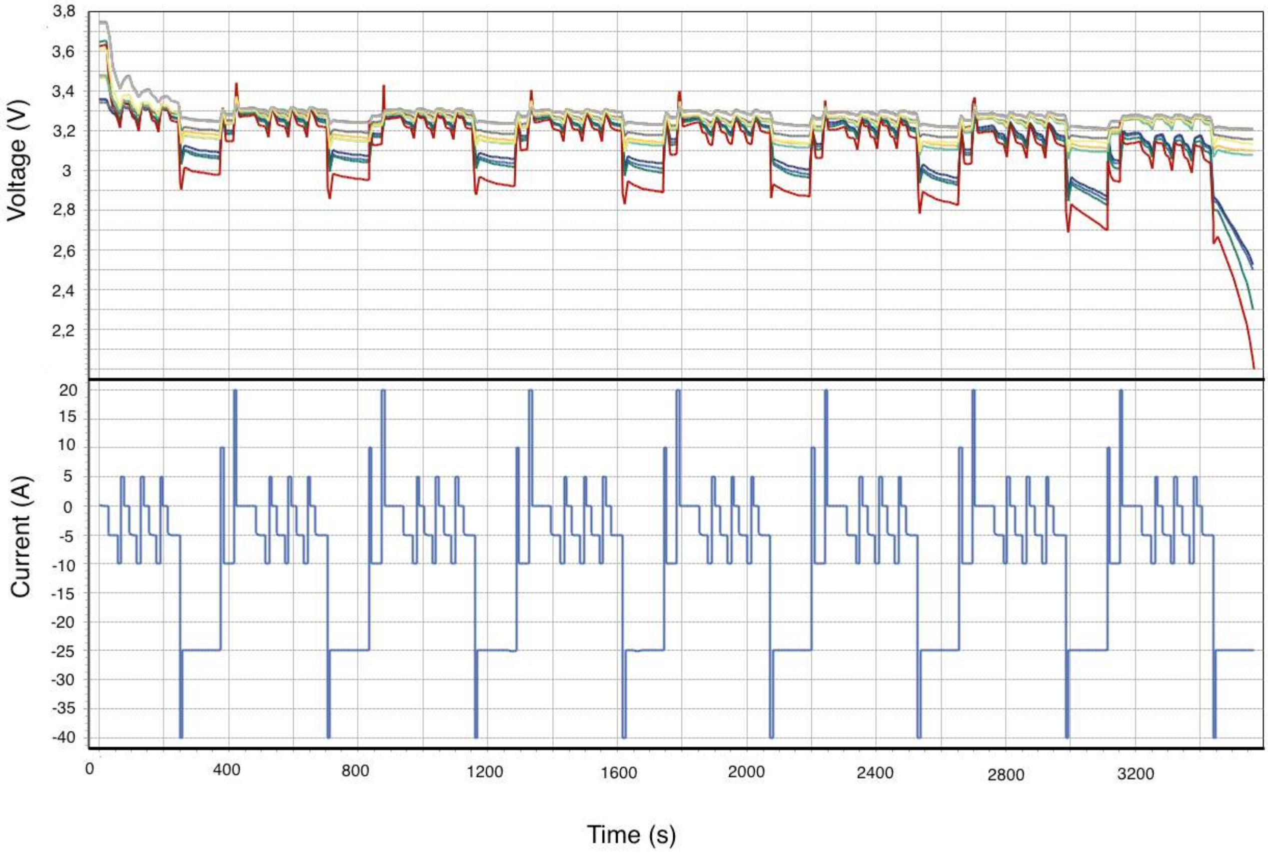
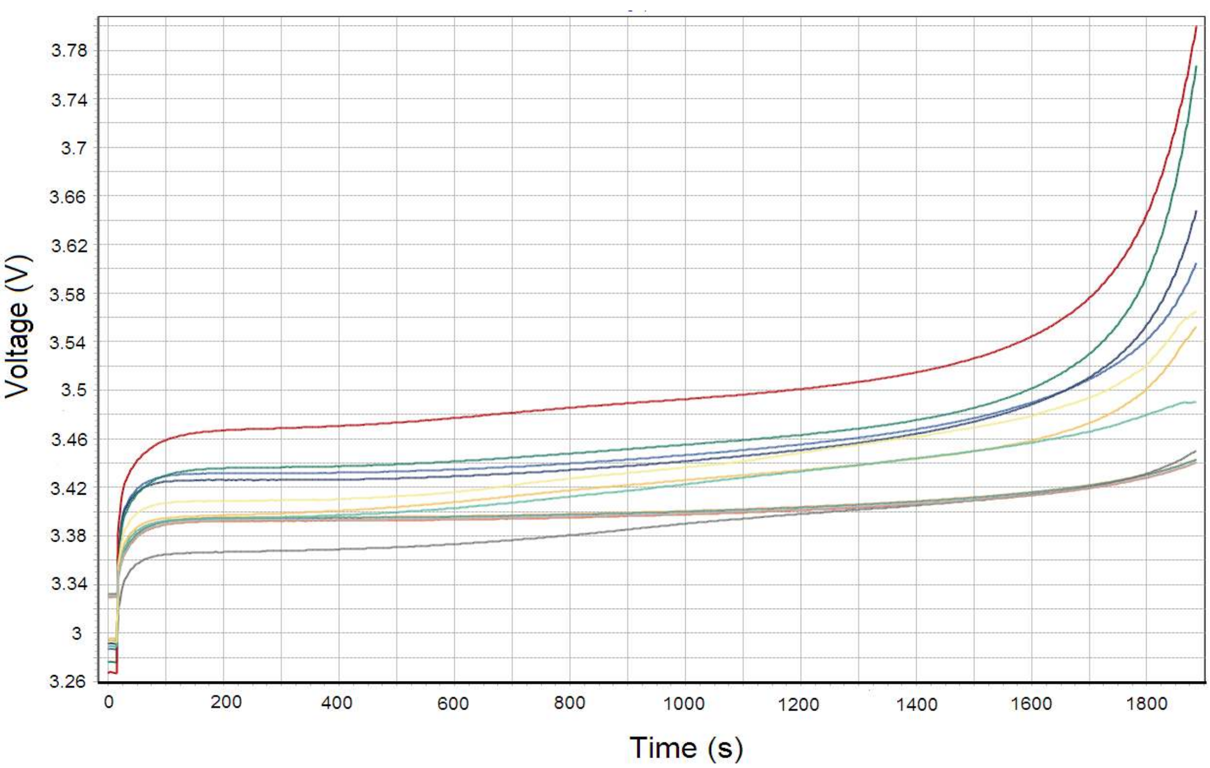


Figure 14. Increasing of variation between the cells during constant current charge without balancing.



4.2. High Power

For hybrid applications, two load profiles have been proposed [28]. They are representing the discharge and charge-rich micro cycles. The discharge cycle will be repeated until 30% DoD has been reached (see Figure 15). Then, the charge sequence will be applied until the upper state of charge limit of 80% SoC is met, as shown in Figure 16. According to the standard, the test should be carried out at 45 °C and the upper discharge and charge current rates are 20 and 12.5I_t, respectively. However, the proposed current rates are too ambitious for most commercial lithium ion batteries. In the framework of a national project in Belgium (Energy Storage project), the life cycle capabilities of seven most promising lithium ion batteries have been investigated at 40 °C. Hereby, it was observed that most battery type as presented in Table 5 are not able to recuperate energy at the earlier mentioned current rates and state of charge conditions. As we see in Figure 17, the cell voltage reaches continuously the upper voltage. So the test sequence has been modified whereby the cell where cycled between 70% and 40% SoC and at 10I_t & 7.5I_t discharge and charge, respectively. From the standpoint of the cycling operating window, the proposed values match much better with the typical battery operating conditions in Prius and Honda Civic, where the state of charge varies between 70 and 50% SoC, although these are NiMH batteries and not Li-ion. The tests have been carried out at same temperature as for the high energy (40 °C).

Figure 15. IEC micro-cycle discharge rich profile for battery electric vehicle [28].

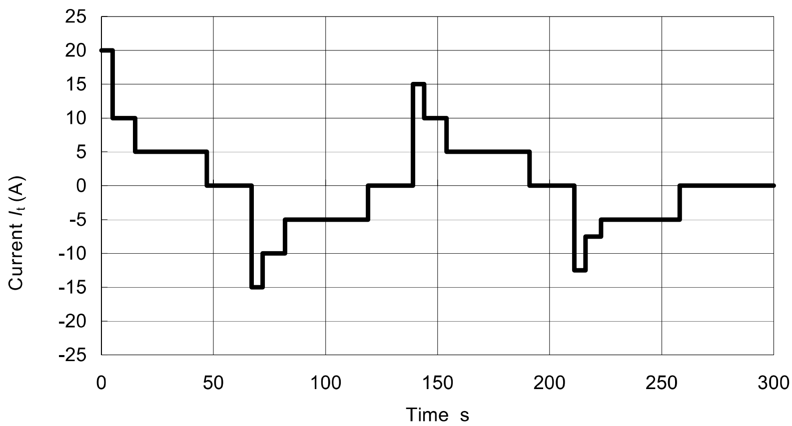


Figure 16. New life cycle method for high power applications [28].

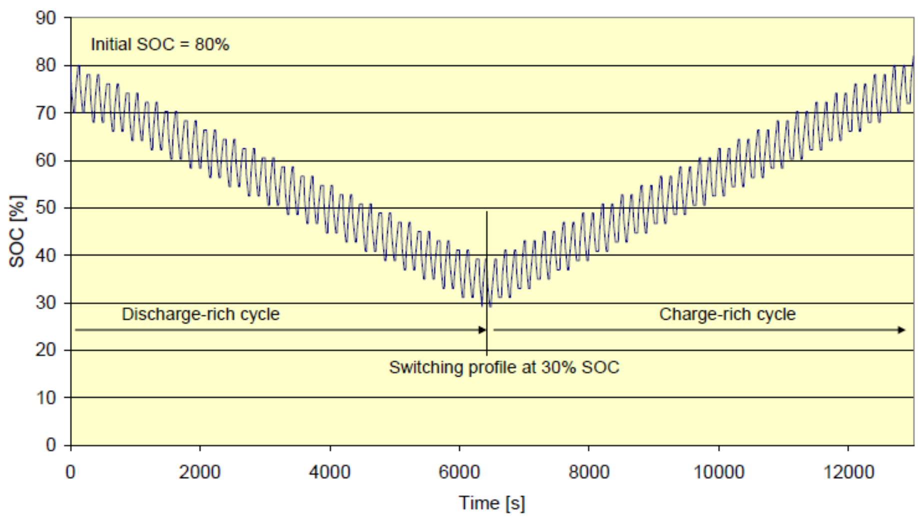
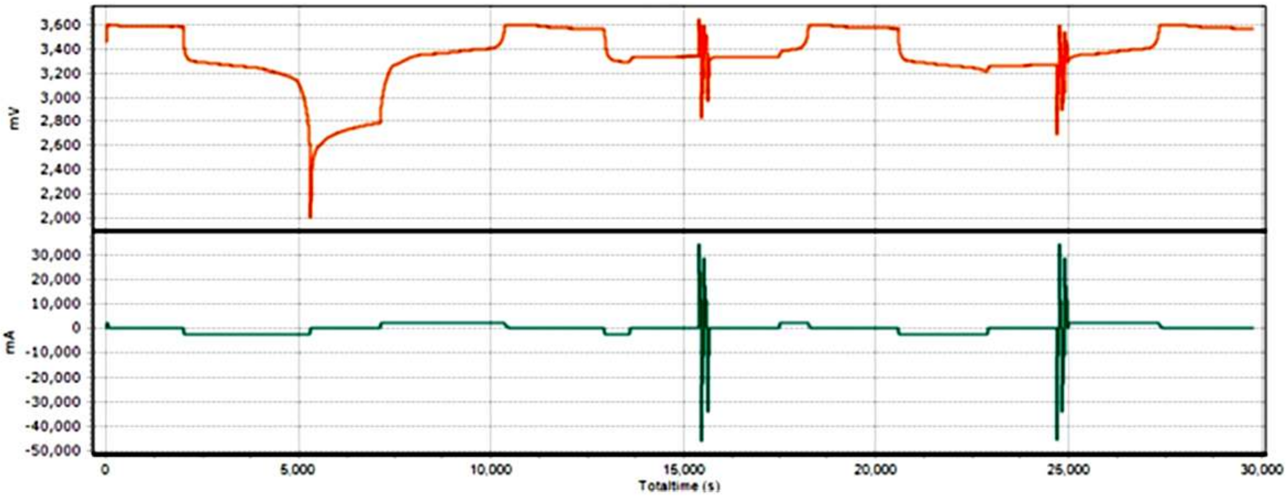


Table 5. Charge and discharge capabilities at 30 and 80% SoC.

Battery	Capacity (Ah)	30% SoC, @ 20I_t	80% SoC, @ 12.5I_t
A	2.3	YES	NO
B	7	YES	NO
C	5.7	NO	NO
D	11	NO	NO
E	12	NO	NO
F	10	NO	NO
G	18	YES	YES

Figure 17. An example of the initial charge and discharge micro cycles.



5. Conclusions

The study of the standardization process for electricity storage devices allows one to draw interesting conclusions about the general impact of standards, proving on one hand how international standardization does provide a direct benefit to technological and societal development through the deployment of electrically propelled vehicles, and highlighting on the other hand the dynamics of the international standardization world. The proposed work for developing for lithium-ion standards shows in general very interesting test procedures in order to determine the performances of a battery pack/system (or a cell). However, the proposed work should be considered for modifications especially in terms of test efficiency and time duration. During this report, a series of modifications have been proposed in order to make these test sequences more comparable and more efficiently. The improved version of power and resistance test developed at the Vrije Universiteit Brussel makes the proposed test more suited to be used in order to determine the power capabilities of the batteries in a very short time, while integrating the energy efficiency test. The life cycle methodology according to the standard IEC 62660-1 does not have a substantial sense, due to the fact that the Arrhenius law cannot be used to in order to compare the result to the manufacturer value. Therefore a new methodology has been proposed allowing one to derive the life cycle of a battery in function of depth of discharge.

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