Insert Switches Inside to Increase Battery Lifespan

Christophe Savard, Pascal Venet, Eric Niel, Laurent Piétrac and Ali Sari

Abstract—This paper shows the possible gain on time before the end of useful time brought by switches addition in a multicell battery. In a first time, it presents a battery electric model. A battery includes many identical electrical energy cells that electrically interact. From a behavioral standpoint, cell performance is measured by fundamental parameters: State of Charge (SoC) and State of Health (SoH). To simulate cell electrical behavior, the Thevenin model or the Nerst model are often used. However, these models do not take into account the cells aging or the possible interactions on aging. A cell ages mainly in two ways: cyclic and calendar. This aging impacts both the elements of the equivalent electrical model and the fundamental parameters (SoC and SoH). Thus, the conventional electric model of a cell does not accurately reflect the cell aging. In this paper, another formal model based on the fundamental curve that relates electrical and behavioral parameters is proposed. It integrates aging into the equivalent electric model estimation. In a second time, in order to validate this model, this cell model is used to simulate parallel-series association. To improve battery lifespan, in addition to the usual balancing techniques, it may be relevant to require some traditional reliability and operating safety solutions. This requires to add switches inside battery. The presented simulation shows adding switches solution is currently not deployed. This is justified in this paper by examining the impact provide on lifespan improvement on an example, which is pretty weak. But it also shows that however, by managing active cells in a different way, adding switches and spare cells can really reach this improvement.

Index Terms—LiFePO4 Batteries, Modeling, SoC, SoH, battery Aging Parameters.

I. CONVENTIONAL MODELS OF A CELL

Batteries often combine a large number of cells [1]. A single cell provides a current Icell with a voltage Vcell, depending on electrode and electrolyte nature, but their values are often insufficient for a common use. The present dominant technology is the lithium-ion, whose voltage Vcell is less than 4.2V. A cell is also characterized by its initial capacity Q, expressed in ampere hours (Ah).

A. Fundamental parameters

As a result, two fundamental parameters are related to the electric charge that a cell can contain. At a time t, a battery is able to store a certain maximum electrical charge, denoted Q0(t) and designated as operational charge. This operational charge decreases over time, according to the modes specified below. A cell stores at this time t an instantaneous electrical charge Q(t), less or equal to Q0(t). The first fundamental parameter, the State of Charge (SoC), defined by the relation (1), represents the ratio between the instantaneous charge and the operational charge.

\[ \text{SoC}(t) = \frac{Q(t)}{Q_0(t)} \]  

(1)

Over time, a cell is no longer able to store the same operational charge. To measure this decrease in performance, due to aging, a State of Health (SoH), expressed in per cent, is defined by the equation (2).

\[ \text{SoH}(t) = \frac{Q(t)}{Q_0} \]  

(2)

A third parameter is the lifespan. For a cell, the nominal lifespan Ld is expressed in cycles. In this paper, T is the dummy variable to express cycles. A cycle corresponds to a complete discharge followed by a complete recharge. The battery lifespan depends upon battery architecture, number of cells, lifespan of each cell and operational environment. When a cell SoH is weakened, it is scrapped. The ISO 12405-4 standard for electric vehicles [2] specifies that the cell end of life occurs when the SoH goes down to 80%. The equation (3) establishes an approximate relation between lifespan, number of cycles and initial charge capacity for Q0(T).

\[ Q_0(T) = Q \cdot \left(1 - \text{Scrap} \cdot \frac{T^2}{T^2_f}ight) \]  

(3)

Fig. 1. Q0 degradation in SLiFePo4.

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C. Savard is a former Ph. D. student at the Ampere Laboratory, UMR CNRS 5005, INSA and University Claude Bernard, Lyon, France, e-mail: christophe.savard@univ-lyon1.fr.

Eric Niel and Laurent Piétrac are with the Ampere Laboratory, UMR CNRS 5005, INSA de Lyon, 20 avenue Albert Einstein, 69621 Villeurbanne Cedex, Lyon, France, e-mail: eric.niel@insa-lyon.fr and laurent.pietric@insa-lyon.fr.

Pascal Venet and Ali Sari are with the Ampere Laboratory, UMR CNRS 5005, University Claude Bernard Lyon, 43 bd du 11 novembre 1918, 69622, Villeurbanne Cedex, France, e-mail: pascal.venet@univ-lyon1.fr and ali.sari@univ-lyon1.fr.

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Fig. 1 shows the operational charge Q0 degradation expressed in cycle number T for a 60 Ah prismatic LiFePo4 cell [3]. This LiFePO4 cell has been subject to accelerated aging tests, under temperature of 50°C. It was discharged with a current one third of its nominal current, in each cycle down to a voltage of 2.5V corresponding to a SoC = 0. Below that, a deeper discharge can cause irreparable internal
damage. It is more accurate to measure capacity when the cell is discharged under a third of its nominal current [3].
Then, the cell is recharged under the same current level up to a voltage of 3.7V in order to obtain a full charge.

B. Thevenin’s models

Electrically, the Thevenin model, shown in Fig. 2, describes fairly accurately the cell behavior [4]. It consists of an ideal open circuit voltage source (OCV) and an equivalent series resistor (ESR) [5].

A simple electrical model enables to quickly determine cell characteristics. The OCV is not measurable because of the voltage drop due to the ESR and thermodynamic equilibrium in the electrolyte [6]. For an online application, the OCV must be estimated by an algorithm or by adaptive methods from cell terminals voltage and current simple measurements [7,8]. To do this, the batteries are controlled by a Battery Management System (BMS) whose main function consists in monitoring cell SoCs and prevents them from overloading or being too deeply discharged [7,9]. For this, the BMS permanently determines the battery cell fundamental parameters [10,11] on the basis of electric measures it make itself with sensors.

C. Nernst model

Other schemes are based on the battery internal chemistry [12]. Another model is often deployed, that of Nernst [13]. It is based on the characteristic curve connecting OCV to SoC, as shown in Fig. 3 for a LiFePO4 cell. The relation is continuous, but not linear. It shows three zones. First, a zone (I) for weak SoCs, between 0 and SL, where OCV quickly increases with the State of Charge from V0 to VL. Second, a linear zone (II), up to SH, where the battery voltage is almost linear. Third, a zone (III) where the voltage rapidly increases from VH to VM when approaching a SoC worth 100%.

The first order Thevenin model is simple, consequently it does not describe all the cell physical and chemical phenomena nor the OCV nonlinear evolution according to the SoC. That is why one of the most commonly used model to describe OCV depending on SoC in BMS is the Nernst model [14], which is describe in the equation (4).

\[
OCV = K_0 + K_1 \cdot \ln(\text{SoC}) + K_2 \cdot \ln(1 - \text{SoC}) \quad (4)
\]

The K0, K1 and K2 parameters are experimentally determined by matching the mathematical model with the actual measured curve. The open circuit voltage is then an increasing function of SoC. Nevertheless, these parameters are only valid for the moment of live to which they are established. Indeed, the characteristic equation evolves with the cell aging and with the temperature [7,15].

In this paper, the next part explains the cell aging modes. Chapter 3 presents a simple way to model a cell by integrating aging and its consequences on fundamental and electrical parameters, by adapting existing model. The following chapter presents a cell modeled by the proposed model example. Then this cell is associated with other identical ones in a battery to firstly compared between the model and an example, secondly to determine if and how adding switches in a battery can increase its lifespan.

II. CELL AGING

A cell has its operational charge Q0(t) which decreases with time, according to a monotonous degradation \( \Gamma \) process [7,16,17]. Apart from apparent recoveries related to the electric charge extraction frequency, as shown in Fig. 1 for around 320 cycles [18], a cell never recovers its lost capacity. This regeneration phenomenon is often due to the environment conditions.

A. Aging ways

A battery ages over time [19]. Even an unused cell sees its instantaneous charge shrink over time. According to the second law consequence: Entropy, or energy degradation, the electric charges trapped in the cell eventually free up over time. The storage temperature is an aggravating factor in aging [20,21]. On the other hand, cyclic aging reduces the cell performances. As a cell is discharged and then charged, a passivation layer is created at the electrolyte and electrode interfaces. After several cycles, the metal regeneration potential of the positive electrode decreases. It loses its porosity, which increases the resistance between the electrode and the electrolyte [22]. The more the operating temperature is high [23] or the more the extracted current is important [24] or the more the energy extracted during a discharge is important [25] and the more this aging will be faster, because of these three aggravating phenomena.

B. Aging consequences

The aging results in a reduction of the cell operational charge and an increase of the ESR. This means that as the cell gets older, it cannot store as much energy as it did before. When it is used in electric vehicle, as ESR increases, it can only deliver less power. When batteries are used in applications requiring power spikes, the ESR degradation is a more relevant factor to measure aging than Q0. The SoH can also be defined as the ratio between the ESR at time 1

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and the initial ESR (ESR₀) [26].

C. Cell dependencies

Each cell ages independently of others when integrated in a battery. Even from the same batch, all the cells do not all have the same electrical characteristics [27]. So, according to their Q₀ and ESR, the cells do not all contribute to the collective effort in the same way. In particular, they have not all supplied the same current, have not heated at the same level or have not all been discharged in the same way [28]. Some of them have weakened (low SoH) before others. Nevertheless, since they are all associated by the battery architecture, the presence of weak cells impacts the others.

D. Switches and control

The modeled switches in this paper are STL135N8F7AG STMicroelectronics (130A, 80V), automotive grade and powerFLAT MOSFET Their technical characteristics are given in Table I. Like any other component, they are not perfect, with opening (t₅₀) and closing (t₄₀) times of a few tens of nanoseconds as well as delay times at opening (t₈₀) and at closing (t₄₀). Since the switching times are much shorter than the used discretization time (30 seconds) used after in the battery model, they are not taken into account in the main simulation. Nevertheless, disturbances can occur during switching. They are the subject of a particular paragraph.

TABLE I. STL135N8F7AG MICROELECTRONICS FEATURES

| I₅₀ | V₉₀max | R₀rON | R₀rONmax |
|-----|--------|-------|----------|
| 160 A | 80 V  | 3.85 mΩ | 4.40 mΩ  |
| t₅₀ | t₈₀ | t₄₀ | t₄₀ |
| 30 ns | 28 ns | 83 ns | 30 ns |

The gate control of the switches is considered optimal. The BMS is not the object of this study, so the control law is not described here, but the subject of other publications, as [29]. For simplicity, we have considered that when V_DS = 0, I_DS = 0 and when the switch is on, a voltage V_DS drop (equation 5) is considered. In simulations, the wiring inductances are neglected.

\[ V_{DS} = \frac{V_{DS\text{max}}}{R_{DS\text{ON}}} \]  

Adding of surplus switches in the battery increases the weight, volume, complexity and cost. In a battery, each switch must be adapted (voltage, power, max current, di/dt, parasitic capacitance ...) according to its use. The addition of a switch per cell increases the battery cost by only 10%.

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III. INTEGRATED ELECTRIC MODEL INCLUDING AGING

To properly simulate the battery overall behavior, it is necessary to simulate the electrical, thermal and the fundamental parameters of each cell and interactions between them. The model presented in this article does not pretend to model globally the whole of a battery but introduces a cell model with architecture dependencies (series, parallel or others) simulated by equations. There also are other aging-less models that describe the battery as contiguous connected submodels [31].

A. Cell model

The Nernst model given by equation (4) has a defect: it is based on logarithms and thus cannot model the boundary behavior of SoC (fully charged or uncharged cell). Based on the characteristic curve of Fig. 3, it is possible to perform a linear polynomial regression to determine an equation that best interpolates the actual curve. However, even a 5-order regression does not match the model to reality. Since the curve is continuously increasing, a regression by parts can be carried out. For low and high SoC values, an exponential equation is suitable. For average SoC values, a linear function is sufficient.

Basing on the two points at the second zone boundaries, defined by (S₀, V₀) and (S₄₀, V₄₀), equation (6) describes relation between OCV and SoC, represented by the dummy variable S, traced in green in Fig. 4.

\[ OCV(S) = \frac{(V_H - V_L)S + V_L S_H - V_H S_L}{S_H - S_L} \]  

For weak SoCs, the exponential equation must include the V₀ value found for SoC equal to zero. This equation is drawn in red. To determine S₀, it is advisable to distinguish on the curve all the exponential part influence. The linear zone could be extended below S=S₀, as it can be seen in Fig. 4 since the linear green curve remains close to the real blue curve. Thus, as seen from the equation (7), when the SoC is equal to one-fifth of S₄₀, the real curve has a value V₄₀ which corresponds to the exponential constant τ in an exponential equation form. Equation (8) describes this zone of the characteristic curve.

\[ \begin{align*}
S &= \frac{S_0}{5} \\
V &= V_0 + \frac{V_L - V_0}{e} \\
OCV &= V_0 + (V_L - V_0) \cdot \left(1 - e^{-\frac{S}{S_0}}\right)
\end{align*} \]

For high SoC, an increasing exponential equation (9) can be established by considering a variable change x as
presented in equation (10), with three constants $x_1$, $x_2$ and $x_3$.

$$OCV_{(H)} = x_1 \cdot e^{x_2} + x_3$$

(9)

$$X = \frac{\text{total discharged amount}}{\text{nominal capacity}}$$

(10)

It is possible to continue charging a cell that has a SoH=1. However, this can lead to catastrophic consequences, such as gas concentration, explosions or fires [32]. Equation (11) models this third zone for the example.

$$OCV_{(H)} = V_H + (V_M - V_H) \cdot e^{\frac{S_1}{1-S_1}}$$

(11)

By merging the respective equations of the three zones, formula (12) gives the complete equation of the mathematical model simulating the characteristic curve.

$$OCV = \frac{S_H(V_L-V_H-V_o)+S_LV_o+(V_H-V_L)S}{S_H-S_L} + (V_L-V_o) \cdot \left(1 - e^{\frac{S_1}{1-S_1}}\right) + (V_M - V_H) \cdot e^{\frac{S_1}{1-S_1}}$$

(12)

B. Aging integration

Besides this electric part, it is necessary to add the aging influence. As the operational charge $Q_0$ evolves as indicated by equation (3), the ESR follows a similar law. Its value doubles, from ESR$_0$ when $T=0$ cycle, while the SoH decreases to the Scrap value [33], according to equation (13).

$$ESR(T) = ESR_0 \cdot \left(\frac{2\cdot \text{SoH}(T) - \text{Scrap}}{1 - \text{Scrap}}\right)$$

(13)

On the other hand, the SoH decreases lower. This reduction can be more or less marked according to the three aggravating factors indicated in part 2.A: extracted charge, temperature and current. To take them into consideration, the drop in SoH can be calculated for each cycle $j$ as indicated by equation (14). The exponent aging, applied for cycling number and $L_c$ is 0.5 by default. Aging is a phenomenon that usually takes place as a function of the square root of time [34,35].

$$\text{SoH}_j = \text{SoH}_0 \cdot \left(\text{A}_0 \cdot \text{A}_1 \cdot \text{A}_2 \cdot \left(\frac{1}{L_c} \cdot \left(\frac{1}{L_c(j)}\right)^{0.5}\right)^j\right)$$

(14)

The three parameters $A_0$, $A_1$ and $A_2$ respectively represent the aggravating influence of the depth of discharge during a cycle, of the cell temperature during the considered cycle $j$ and of the maximum extracted current. Their values are determinable by equations (15) to (17). The cell nominal current $I_{nom}$ is the current it can provide for an hour before being discharged.

$$A_d(j) = \left(\frac{\text{SoC}_0(j)-\text{SoC}_{min}(j)}{\text{SoC}_0(j)}\right)^{0.6}$$

(15)

$$A_T(j) = e^{-\frac{1}{\text{ref}} \cdot \frac{1}{\text{ref} - 1}}$$

(16)

$$A_e(j) = \frac{1}{\text{nom}}$$

With SoC$(j)$ is the value of SoC at the beginning of the cycle $j$; generally 1 if the cell has been fully charged. SoC$_{min}(j)$ considers the minimum value achieved by the SoC before recharging. The different curves showing the influence of DoD in aging that can be found in the literature show that the lifespan is impacted when a cell is subjected to a cycling involving a certain level of DoD. The larger the DoD is, the less important the lifespan is. If, for a weak DoD, $L_4 = L_{max}$ and for a high DoD, $L_4 = L_{min}$. In first approach, it can be estimated that the aging aggravation factor $A_e$ is given by the ratio between these two lifespans. It can then be determined an influence parameter of the DoD, denoted $\rho$, to be determined experimentally. Parameter $\rho$ is taken over in the general case of the formula (15). If the DoD has no influence, this corresponds to $\rho = 0$. If a DoD of 100% at each cycle implies a division by two of the lifespan, that corresponds to $\rho = -1$. Typically, $\rho$ is close to -0.25 [36,37].

$A_e$ parameter follows an Arrhenius law with values for activation energy $E_a$ ranging between 0.4eV and 1eV (typically 0.7eV). $T_{ref}$ is the Kelvin degrees temperature used by the manufacturer to give its reference lifespan $L_c$. $k_B$ is the Boltzmann constant. Cell temperature evolution can be calculated [38] and measured. Based on previous work, including [39,40,41], in a constant current regime, the cell temperature increases with the time almost linearly.

C. Cell association

The different ways of arranging the cells in a battery, in order to meet the external load specifications, have already been the subject of several publications [42-46]. Their respective reliability has been analyzed in [30]. If today, batteries are often calibrated to provide just their rated current, sometimes they include some extra cells. These extra cells are not used as redundant cells, to replace a faulty cell, but as active cells. This means that, for a normal use, all the active cells are maximally solicited at their nominal current. It has been shown in [46], that added spare cells would not improve lifespan unless resources are dynamically driven. On the other hand, by means of serial or parallel connections between cells, these connected cells share either the same current or the same voltage. Since they have neither the same electrical nor fundamental parameters, this leads to balancing currents between cells in parallel and to interactions between their SoCs. Nevertheless, it has been demonstrated in [41] that self-balancing in a parallel connection does not lead to a perfect convergence of the cell SoHs. However, with a classical balancing and without dynamic resource allocation, the battery can have cells with very disparate SoH. The oldest cell becomes its weak point.

IV. APPLICATION

Also, to validate the model described above, it is first proposed to simulate a single cell and study its aging in comparison with the aged cell data. Then, a cell association within a Parallel-Series architecture Battery (PSB), i.e. a series connection of parallel cell, is also be simulated. A
comparison is proposed on the use of switches associated with cells: firstly, by activating only a part of the cells so that they supply their nominal current. On the other hand, all the cells are activated. Finally, the cells to be activated are chosen by an optimization algorithm.

A. Single cell aging

To do this, the LifePO₄ cell that was used to illustrate the first chapter is simulated using Matlab with the equations presented in the previous chapter, under cycling by a repetitive cycle of 70% discharge, complete recharge and relaxation, performed under cell nominal current. Current is constant in each phase. The discharge time is then 42 minutes, as well as the recharge time. The losses are neglected so as to maintain an identical duration and assuming that the phase with constant current allows a complete recharge. At the end of recharging, the cell must be subjected to a constant voltage (CV) regime. The management as such of the CV mode is not the subject of this paper. It is considered optimal. A rest period of identical duration is then observed. The simulated cycle lasts 2 hours 6 minutes. In a first step, with the data of Fig. 4, it is possible to determine the fundamental equation of the tested cell, with reference to equation (12). Its literal values is given by formula (18) and reported in Fig. 5 to compare.

\[
OCV = 2.76 + 0.115 \cdot S + 0.474 \cdot (1 - e^{-15.5\cdot S}) + 0.06 \cdot e^{66.7\cdot (S-1)} \quad (18)
\]

Then, with the regular cycling, the cell SoH simulation can be compared to that measured, as shown in Fig. 6 for a single cell. The slight recovery phenomenon [18] are not taken into account by the model, as announced. Apart from this, the results of the simulation are close to the actual results, the simulated curve often being below the real curve. It should be possible to refine the model by adding the fact that when a cell reaches its second half of life, sometimes aging accelerates [47].
Comparing the SoC curves, it appears that when three cell stacks are solicited, the cells are discharged by 70%, as expected. With four active cell stacks, these are logically discharged less, by only 52.5%. This reduction request allows the battery to have a longer lifespan: the SoH reaching the minimum value of 0.8 for 40 cycles instead of 38 in this example. Using four cells instead of three allows a lifespan increase of +5%. The SoH decreases in the intended way, with a different slope for each cell.

The model also takes into account the operational charge decline, which is reflected in the decrease in the OCV maximum and minimum values with the cycle number increase, because the SoC variation increases with aging. These results show that the model reacts as expected, as much for a single cell as for a several cell association. In this way, it can be used to simulate different associations of the same types of cells within a battery, according to the same structure and according to different architectures.

C. Model validation

The increase in lifespan does not justify the number of additional cells (+5% against a third of cells in addition). Nevertheless, the addition of switches allows to choose in each row which three cells are active and which is placed at rest. To optimize the battery lifespan, the cell which is placed at rest in each row must be the weakest, with regard to a precise criterion. This requires having a high-performance BMS, both in the management of control and in the analysis of the measurements made on each cell. The consequences of poor synchronization are discussed below in point 4.4.

More work is needed to validate the model: examine how the PSB cell parameters evolve, dynamically managed. In a classic PS, there are no switches. The technique currently deployed to improve the battery lifespan is balancing [28,48]. It consists of balancing the electrical charges contained in the cells. However, if this operation really acts on the SoC, its influence on the SoH is indirect because it only acts on the aggravation parameters, not on the intrinsic aging of the cells. Balancing can bring about a 10% lifespan improvement [49]. It is possible to manage by the BMS the battery including the switches, in Fig. 7, by making active on each row only the cells considered the best. This performance indicator can be SoC, SoH or temperature. Fig. 9 represents the evolution of SoC, SoH and OCV with a cell dynamic allocation by SoH, for row 2 cells. For each row, at each cycle ending, during the relaxation phase, the weakest SoH cell is isolated, the others being activated.

The results obtained with this formal model correspond to others obtained with other tools [29], which validate the model presented. Indeed, the SoH curves show that the cells all age at the same rate. This leads to a 53 cycle lifespan. Thus, dynamic management, in this example, has improved the lifespan by 40%. This gain offsets the additional cost in BMS calculating performance and in adding switches. These results are however valid provided that the switches have sufficient reliability and especially that the BMS has a computing capacity and a fairly fast reactivity. The best is to have a soft switching when the battery is in the relaxation phase, which can be more complicated if the battery is used...
continuously, without relaxation phases. The gain in lifespan is greater than battery additional cost of 10%, worth 40% in the case study.

![SoC-based algorithm 4-column battery simul. 3](image)

The impact of adding additional cells dynamically managed can be estimated by comparing the minimum values after 38 cycles on the Fig. 8a curves versus on the Fig. 9. Indeed, for the end of battery life at 38 cycles, the weakest cell of the basic solution has a SoC close to 0.17 and OCV = 3.23V. The SoHs of the cells are between 0.80 and 0.82. When an additional cell is added and the SoC-based optimization algorithm is deployed, the weakest cell of the base solution has a SoC close to 0.26 and OCV = 3.25V; the SoHs of the cells are between 0.82 and 0.83. For the same run time, the SoC at the end of a cycle is clearly higher with the optimization algorithm. The cells thus benefited from resting phases which allowed them to age less quickly.

D. Switching disturbances

Commutations of the study switches can make disturbances. It appears that three types of risks really exist. By considering in parallel two sets (A) and (B) with a switch in series with a cell, and associate them in series with a third set (C), as shown in the diagram of Fig. 10a, all cases combining opening and closing in advance or on late can be studied. A simulation is carried out under LTspice, to show the influence of an imperfect synchronization of the openings and the closings of the switches, in discharge mode. The combinations tested are given in Fig. 10b, by controlling the voltages VGS of each MOSFET with the function "Pulse". The current shapes are given in Fig. 10c. The cells are replaced by their equivalent first order Thévenin scheme, with disparities in OCV and ESR (respectively 3.7V - 20mΩ, 3.72V - 21mΩ, 3.65V - 22mΩ).

![PS Switching disturb analysis](image)

The current supplied by the battery (Fig. 10 blue curves) has no current peaks, apart from a slight peak when, (C) remaining open, one of the switches (A) or (B) closes while the other one was before. Fig. 10d zooms into this phenomenon. Micro-cuts can occur when the current has to move from one parallel branch to another, the activated switch closes after the other opens. On the other hand,
current peaks may appear internally, due to the parasitic capacitances of the MOSFET. This is the case when, in a row, only one switch goes ON, all others remaining OFF. In this case, a parasitic current flows between the cells in parallel. This current is more important if at least one switch is ON in the other rows (Fig. 10e). A second risk appears if in a row, a switch turns ON before the one it has to replace goes OFF (Fig. 10f). The cell in series with the second switch supplies the first before the currents are balanced. It is therefore important to choose the components to limit parasitic capacitance $C_d$ and make sure to reduce current peaks during transition.

V. CONCLUSIONS

The interactions between the physical (temperature, current) and electrical ($Q_b$, OCV, ESR) parameters of the cells can be simulated in the same model. In the presented model, built around the characteristic curve between OCV and SoC, the SoH fundamental parameter is also modeled. The main elements influencing aging (high currents, depth of discharge, temperature) are integrated into the model.

Thus, it is possible to simulate, with this cell model, any lithium-ion cell battery. To perfect the model, it is also possible to complete it by including the thermal relationships existing between the cells grouped in the same space [50]. This model allows to perform simulations and comparisons between different battery architectures and different cell management modes. The paper presents a formal model under Matlab, integrating aging and relaxation phenomenons. It can be used directly in code to simulate different associations between cells and switches. Moreover, the model developed demonstrates that the addition of switches does not intrinsically increase the battery lifespan unless the switches are used to dynamically control the cell aging.

A PSB (parallel-series architecture battery) is describe in the paper to validate this cell model. The model is validated by an expected battery behavior. This study shows that the addition of some surplus cells and switches can improve the battery lifespan by a little. To really improve lifespan, the weakest cells must to be put at rest. The temperature impact is assessed through aggravating aging. The additional switches could contribute to increase the system temperature. The simulation of this temperature average rise could be studied to determine if it would contribute to reducing the performance in terms of improvement of the lifespan.

The lifetime gain related to completeness was described in [49]. It appears that this addition is relevant as long as the cells are dynamically managed. This addition of switches also implies having a high-performance BMS, both in the management of commands and in the analysis of the measurements made on each cell. Adding extra cells and control switches improves the lifespan for a PS architecture battery, for more important space, manufacturing and management cost.

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Dr. Savard received a gold scarf from Prevention Routière Association for the facilities he piloted in making secure exit schools. He writes a book en 2016 about electrical energy storage.

Christophe Savard was born in Ardennes, France in 1967. He is an Automatic Electronics and Computer science engineer from INSA Toulouse. He received the Ph.D degree in electrical engineering in 2017 from INSA Lyon, University of Lyon. He also received a M.S. degrees in Microelectronics at the University of Toulouse in 1990 and a M.S. degrees in Electrical Engineering from the University of Lyon on 2015. He teaches reliability, RAMS and maintenance in the University of Lyon. His current research concerns the storage of electrical energy, the reliability of systems and the attractiveness of territories.

He began a career as an engineer then a manager for French territorial local bodies, the reliability of systems and the attractiveness of territories.

University of Lyon. His current research concerns the storage of electrical energy, the reliability of systems and the attractiveness of territories.