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**Sevdari, Kristian; Marinelli, Mattia; Pastorelli, Francesco**

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# Overview of EV battery types and degradation measurement for Renault Zoe NMC batteries

Kristian Sevdari, Mattia Marinelli, Francesco Pastorelli
*Department of Wind and Energy Systems*
*Technical University of Denmark (DTU)*
Roskilde, Denmark
{krisse; matm; frapa}@dtu.dk

***Abstract*—This paper presents a comprehensive review on electric vehicle (EV) battery technologies and an empirical analysis of degradation in Renault Zoe NMC batteries. The extensive review of 50 commercial EV models identifies the dominance of NMC and LFP batteries and changes in composition, such as the reduction of cobalt in NMC batteries. Specifically, the average capacity for NMC type batteries is 68.9 kWh, 62.4 kWh for LFP, and 104.6 kWh for NCA batteries. Simultaneously, we delve into degradation patterns of Renault Zoe models through non-invasive CANBUS measurements. This approach reveals the influence of usage patterns and calendar aging on NMC battery health. Our findings show significant variability in degradation among 2018 R90 models, indicating the critical role of driving behaviors in battery longevity. The study also notes a potential degradation stabilization in the older 2013 Q210 model. These insights contribute to advancing the understanding of battery health in EVs, supporting the development of more sustainable and efficient electric mobility solutions.**

***Index Terms*—Battery type, Battery degradation, Battery management system, Electric vehicles, State-of-Health**

## I. Introduction

The uptake of electric mobility is closely related to advancements in battery technology where lithium-ion batteries dominate the EV market [1]. The authors of [2] suggest that lithium-ion batteries for EVs mainly include lithium cobalt oxide (LCO), lithium manganese oxide (LMO), lithium iron phosphate (LFP), and nickel manganese cobalt oxide (NMC) types. While LCO was initially preferred for its high energy density, concerns over cost and safety have led to the rise of LMO, LFP, and NMC, with NMC being notable for its high energy density. LFP batteries, despite their lower voltage, are valued for being environmentally friendly, cost-effective, and reliable in EVs [3]. Consequently, the authors of [4] summarize and compare even lithium titanate oxide (LTO) (Mitsubishi's i-MiEV) and nickel cobalt aluminum oxide (NCA) types. NCA batteries are known for their high energy density, which makes them particularly useful in applications where weight and space are critical. The addition of aluminum not only helps in stabilizing the battery but also enhances its lifespan and safety compared to other lithium-ion batteries with high nickel content. Comparatively, NCA batteries have a higher energy density than NMC batteries, but they might be slightly less stable and more expensive due to the high content of nickel and cobalt [5]. However, the technological development of batteries is progressing rapidly and new technologies are being implemented in the mobility domain [6].

Moreover, battery life falls short of satisfying the long-term user demands [7], thus there is a growing need to understand the degradation mechanisms to extend the lifetime of the vehicle. The authors of [8] divide into four categories the key issues of the lithium-ion battery degradation: 1) "influence factor" (e.g. design, production, and application); 2) "side reactions" (e.g. electrode particle cracking, etc.); 3) "degradation mode" (e.g. loss of active material, resistance increment, etc.); 4) "battery experiences" as capacity or power fades. This investigation focuses on how the application type influences the battery capacity because design and production are outside the control of the end user. Consequently, studies have investigated the influence of battery working conditions on the degradation rate [8]. These can be summarized as i) high or low-temperature [9], [10], ii) high or low state-of-charge (SOC) [11], [12], and iii) high charge or discharge rate [13]. Subsequently, field validation and modeling methodologies for degradation rates for LFP [14], NMC [15], LMO [16] have been proposed. A simplified model based on field measurements for NMC type is presented in [17]. Here, the authors group the degradation process into calendar aging and cycle degradation. The same methodology is used in this paper.

Therefore, in this paper, we review the battery types implemented in the current EV fleet to provide a recent view of market development. The literature review highlights the available lithium-ion battery types, however, fails short on providing the market view. The second contribution of the paper is the degradation investigation of four identical Renault Zoe R90 vehicles and one Renault Zoe 24. The former are from 2018 while the latter is from 2013. This provides a rare opportunity to investigate five-year-old vehicles that are identical in battery technology (NMC), however, with a different usage pattern. The remainder of this paper is as follows. Section II presents the methodology and vehicles under test. Consequently, Section III provides a review of the battery type of 50 commercial EV models. Subsequently, Section IV introduces the results from battery degradation measurement of Renault Zoes. Lastly, Section V concludes the paper with lessons learned.

## II. Methodology

On the one hand, the review of EV battery types is conducted on the available information from automakers and using the online "EV database" website [18]. On the other hand, the methodology used in this paper to measure the battery energy content and other electrical parameters is based on CANBUS measurements. This method prevents vehicle dismantling and has been proven to be successful in numerous studies on battery degradation [19] and vehicle data analytics [20]. For the Renault Zoe case, we use the on-board diagnostics port (OBDII) dongle connected by Bluetooth to an Android phone with the CanZe application. CanZe application provides a large amount of real-time data from the vehicle's internal battery management system (BMS) and controller units. Most importantly, it provides data regarding DC battery current and voltage, available energy content, usable and real SOC, state of health (SOH), DC power, battery odometer, battery temperatures, battery cell voltages, charging cycles, etc. Two different Renault Zoe models are under investigation, Renault Zoe R90 (2018) and Q210 (2013). For the former, we have three identical vehicles produced on April-June 2018, however, driven in a substainably different margin. The vehicles are named "Zoe2", "Zoe4" and "ZoeS". One of the vehicles, "Zoe4", is driven approximately 10,000 km after five years; hence, it can serve as a baseline for battery calendar aging. Subsequently, the other two vehicles can provide valuable learning about battery degradation from increased transportation usage. In addition, vehicles are consistently charged to 100% SOC and have operated only in Danish weather. The latter vehicle (Q210-named "ZoeF") under consideration has approximately 100,000 km on it and has been driven both inside and outside Danish cities. Typically, the charging pattern consists of four times a week charging at 22 kW to reach 90%-100% battery capacity, and four times a month charging at 43 kW to reach 80%-90% when embarking on longer trips between the Sjaelland and Jylland regions in Denmark.

## III. EV battery topologies overview

As mentioned previously, the literature highlights six main types of lithium ion battery typologies for EVs. However, in commercial terms, NMC and LFP are dominant. The available data for relatively recent vehicles suggest that the LCO, LTO and LMO types are no longer present. While, NCA was observed in expensive models such as Tesla Model S/X and Audi Q8 e-tron 55. Furthermore, based on data for 2022, the authors of [5] suggest that the EV battery market is divided between 60%-NMC, 30%-LFP, 8%-NCA and 2%-other types. Extending on these data and using public available resources, Table I presents the battery types for 50 EV models. The survey identifies 38 EV models or 76% that use a NMC type. LFP ranks second with nine models or 18%. Lastly, NCA ranks third with three models or 6%. However, while the NMC type dominates the available models, sales of the LFP type EVs are significantly higher driven by Tesla and BYD.

Moreover, it is worth mentioning the evolution of the NMC battery type. There has been a trend toward reducing the use of cobalt, which is more expensive, in favor of increasing the proportion of nickel. This shift not only is cost-effective but also enhances the energy density of the batteries. For example, the battery cathode NMC532 uses 50% nickel, 30% manganese and 30% cobalt. As a result, we observe NMC622, NMC721, or even NMC811 battery cathodes that contains as much as 80% nickel and only 10% cobalt. Further advances in this field are underway, with research focused on developing NMC955 cathodes, which propose to increase the nickel content to 90% [5].

Another interesting observation is that high-end manufactures are opting NMC for NCA type. This comes with the benefit of lower battery costs without compromising energy density, charging power, and life span. Another trend can be observed for mid-range vehicles following the LFP battery type. Automakers are sacrificing energy density for lower battery cost, extended life span, and higher safety. Finally, the average nominal battery energy content for the reviewed vehicles is 70.5 kWh, with the maximum and minimum being 120 and 40 kWh, respectively. The NMC type average nominal battery capacity is 68.9 kWh, while for LFP is 62.4 kWh, and for NCA is 104.6 kWh.

## IV. Degaradation of Renault Zoe R90 (NMC)

The process of measuring the battery energy content is as follows. The vehicle is used until it shuts down and afterwards it is fully charged. This process takes place in a controlled temperature environment (18-20 C) within the DTU-EV Laboratory. The battery energy content can be divided into four levels: i) lower limit (limit driving), ii) lower buffer (turtle mode), iii) available energy, and iv) upper (buffer) limit (not accessible). These levels are a consequence of the BMS strategy followed by Renault and can be found in all vehicles tested. The literature suggests that NMC cell batteries can have an open circuit voltage between 2 and 5 V. Consequently, the authors of [21] characterize a safety operation area between 2.5 and 4.2 V. Thus, BMS continues to manage the voltage level in cells to maintain an optimal voltage operation window. The cell voltage operation window affects the full battery operation as the battery pack voltage will go as low as the lowest cell allows and vice versa.

Figure 1 visualizes the battery energy content and the corresponding cell voltages based on the measurement of 23 March 2024. Here, one can observe two different SOC values. On the one hand, it is the "displayed SOC", which means the SOC displayed in the driver information system. The displayed SOC corresponds to the limitation of the available energy content of the battery. On the other hand, it is the SOC stored in BMS, which controls the entire energy content of the battery. Another notable observation is the corresponding cell voltages with the battery energy content. As expected, the cell voltage imbalance increases when you reach the extremes. Figure 2 presents the results of the battery degradation from calendar aging and in relation to kilometers driven. At the first measurement (20 July 2023), Zoe4 had 10 145 km and 1.84 kWh degradation, while Zoe2 had 18 020 km and

TABLE I: Review of battery typologies for mainstream EVs.

| No | Vehicle | Model | Battery voltage architecture [V] | Battery energy content [kWh] | Available battery energy | Battery topology | Production year |
|---|---|---|---|---|---|---|---|
| 1 | Audi | e-tron 55 quatro | 400 | 95 | 86.5 | NMC622 | 2020-2022 |
| 2 | Audi | Q8 e-tron 55 | 400 | 114 | 106 | NCA | 2022- |
| 3 | BYD | Atto 3 | 400 | 62 | 60.5 | LFP | 2022- |
| 4 | BYD | Seagul | 800 | 84 | 82.5 | LFP | 2023- |
| 5 | BYD | SEAL | 400 | 73 | 71.8 | LFP | 2024- |
| 6 | BMW | i3 | 400 | 42.2 | 37.9 | NMC622 | 2018-2022 |
| 7 | Citroen | e-Berlingo XL | 400 | 52 | 50 | LFP | 2024- |
| 8 | DS | 3 E-Tense | 400 | 54 | 50.8 | NMC811 | 2022- |
| 9 | Fisker | Ocean | 400 | 73 | 71 | LFP | 2023- |
| 10 | Hyundai | Kona | 400 | 67.5 | 64 | NMC622 | 2018-2023 |
| 11 | Hyundai | Ioniq | 400 | 40.4 | 38.3 | NMC622 | 2019-2022 |
| 12 | Peugeot | e-2008 | 400 | 54 | 50.8 | NMC811 | 2023- |
| 13 | Peugeot | e-3008 | 400 | 77 | 73 | NMC | 2023- |
| 14 | Peugeot | e-308 | 400 | 54 | 50.8 | NMC811 | 2023- |
| 15 | Peugeot | e-208 | 400 | 51 | 48.1 | NMC811 | 2023- |
| 16 | Polestar | 2 LRDM | 400 | 78 | 75 | NMC | 2023- |
| 17 | Polestar | 3 LRDM | 400 | 111 | 107 | NMC | 2022- |
| 18 | Porche | Taycan | 800 | 79 | 71 | NMC721 | 2021-2023 |
| 19 | Renault | Zoe R90 | 400 | 44.1 | 41 | NMC622 | 2016-2019 |
| 20 | Renault | Zoe Ze50 | 400 | 54.7 | 52 | NMC721 | 2019- |
| 21 | Renault | Megan-tech | 400 | 65 | 60 | NMC | 2022 - |
| 22 | Smart | 1-Pro | 400 | 49 | 47 | LFP | 2023- |
| 23 | Smart | 3-Pro | 400 | 49 | 47 | LFP | 2024- |
| 24 | Jaguar | i-Pace 400 | 400 | 90 | 84.7 | NMC622 | 2020-2023 |
| 25 | Kia | E-Niro/E-Soul | 400 | 67,5 | 64 | NMC | 2018- |
| 26 | Kia | EV6 | 800 | 77.4 | 74 | NMC | 2021- |
| 27 | Mercedes-Benz | EQC 400 | 400 | 85 | 80 | NMC622 | 2020-2023 |
| 28 | Mercedes-Benz | EQS 450+ | 400 | 120 | 107.8 | NMC811 | 2021-2023 |
| 29 | MG | 5 LR | 400 | 61.1 | 57.4 | NMC | 2022- |
| 30 | MG | 4 | 400 | 64 | 61.7 | NMC | 2022- |
| 31 | Mini Cooper | E | 400 | 40.7 | 37 | NMC | 2023 - |
| 32 | Mini Cooper | SE | 400 | 54.2 | 49 | NMC | 2021-2024 |
| 33 | Nissan | Leaf | 400 | 40 | 36 | NMC532 | 2017- |
| 34 | Nissan | LEAF e+ | 400 | 62 | 59 | NMC532 | 2019- |
| 35 | Nissan | Ariya | 400 | 91 | 87 | NMC | 2022- |
| 36 | Tesla | S | 400 | 100 | 95 | NCA | 2016- |
| 37 | Tesla | Y | 400 | 60 | 57.5 | LFP | 2020- |
| 38 | Tesla | 3 | 400 | 60 | 57.5 | LFP | 2017- |
| 39 | Tesla | X | 400 | 100 | 95 | NCA | 2016- |
| 40 | Volkswagen | ID3 Pro | 400 | 62 | 58 | NMC721 | 2021- |
| 41 | Volkswagen | ID4 Pro | 400 | 82 | 77 | NMC721 | 2021- |
| 42 | Volkswagen | ID5 Pro | 400 | 82 | 77 | NMC721 | 2022- |
| 43 | Volvo | XC40 | 400 | 69 | 67 | NMC | 2024- |
| 44 | Volvo | EX30 | 400 | 69 | 64 | NMC | 2024- |
| 45 | Xpeng | P7 LR | 400 | 86.2 | 82.7 | NMC | 2020- |
| 46 | Xpeng | G9 LR | 800 | 98 | 93.1 | NMC | 2022- |
| 47 | Zeekr | X LR | 400 | 69 | 64 | NMC | 2023- |
| 48 | Zeekr | 001 Privilege | 400 | 100 | 94 | NMC811 | 2023- |
| 49 | Opel | Corsa-e | 400 | 51 | 48.1 | NMC811 | 2020- |
| 50 | Opel | Ampera-e | 400 | 62.2 | 58 | NMC622 | 2017-2020 |

2.05 kWh degradation. As mentioned above, Zoe4 is used as a benchmark. Thus, the difference in km driven (7875 km) reflects the increase in degradation by 0.21 kWh (or 0.47 % more). The second measurement (20 December 2023) showed a difference of 6442 km between Zoe4 and Zoe2 that corresponded to 0.36 % degradation increase to the calendar aging. The final measurement (23 March 2024) compares the baseline Zoe4 with ZoeS, which have a 41 340 km odometer difference corresponding to an additional degradation of 0.677 kWh (1.5 %), see Fig.2.

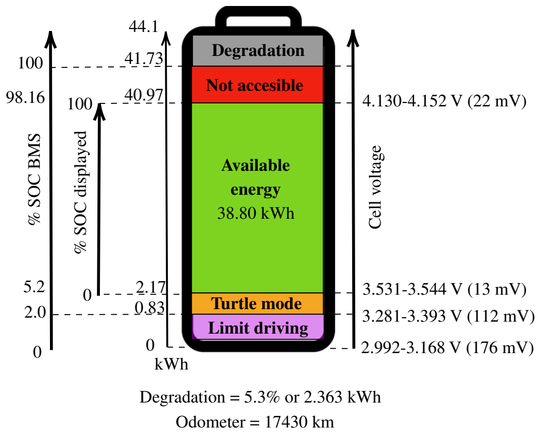


Fig. 1: Visualization of the battery energy content and the corresponding cell voltages based on the measurement of 23 March 2024 for Zoe4.

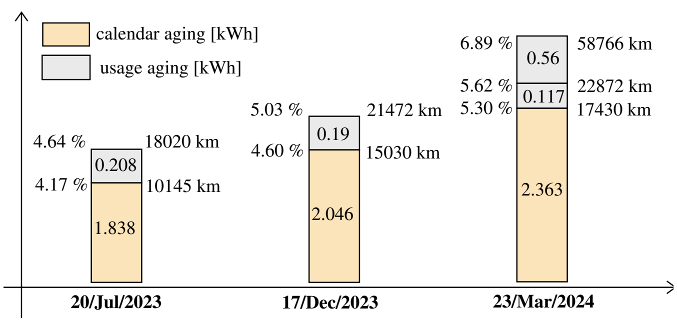


Fig. 2: Degradation comparison between Zoe R90.

Furthermore, Fig. 3 provides information on the energy content of the battery and how BMS reacts to the aging process. Before drawing conclusions from data, it is important to note that there is uncertainty about the quality of the data. For example, it is difficult to prove the measured values in the 0.1-0.01 kWh range. Thus, we assume that the values read from the vehicle onboard diagnostics are correct. Data show that BMS optimizes the battery to deliver the optimal available energy content. Thus, the vehicle user does not experience the complete degradation. However, the higher limit of BMS SOC increases with time (e.g., for Zoe4 from 97.6 % to 98.16 %). This means that BMS tries to maintain the same available energy by releasing energy from other parts that serve as energy buffers for the battery. Consequently, the measurements suggest that BMS is trying to keep the same minimum or maximum cell voltage levels, see Table II. In addition, the cell voltage disbalance is relatively similar, thus suggesting that BMS makes sure to charge or discharge accordingly the battery cells. Finally, Table II also provides the results of the degradation measurement for Renault Zoe Q210 (ZoeF). In a 10-year period the vehicle has lost 4.56 kWh or 17. 6 % compared to 25.9 kWh. A careful observation is the minimal amount of degradation measured on the second measurement (after four months). For the younger Zoe generations (Zoe4 or Zoe2), the consecutive measured degradation averages 0.23 kWh. In contrast, ZoeF experiences only 0.04 kWh of degradation. This suggests that after 10 years, ZoeF has reached saturation on the degradation curve.

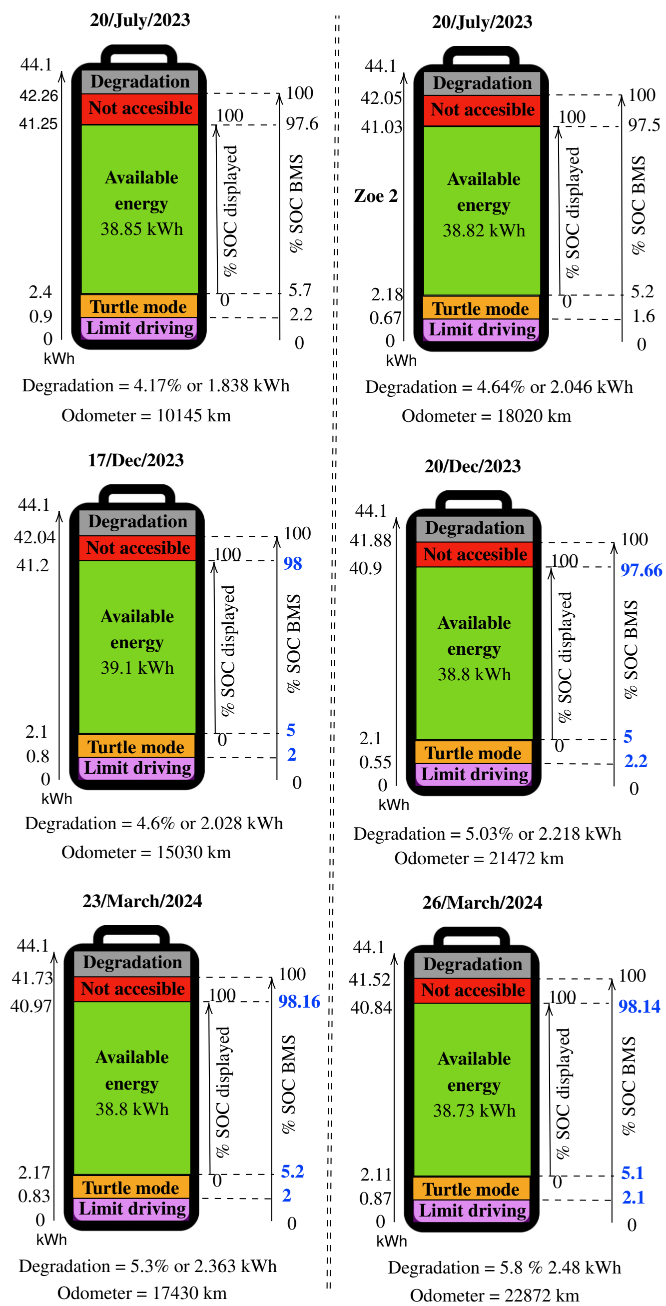


Fig. 3: Battery energy content measurements for (left)"Zoe 4" and (right)"Zoe 2".

## V. Conclusions

In this paper, we presented a dual-focused analysis encompassing both a comprehensive review of current commercially

TABLE II: Field measurements for Renault Zoes.

| Time | Real usable battery [kWh] | Degradation [kWh] | Odometer [km] | Min cell voltage [V] | Max cell voltage [V] | Full charging cycles | Partial charging cycles | SOH [%] Renault | SOH [%] measured |
|---|---|---|---|---|---|---|---|---|---|
| **Renault Zoe R90 (Zoe 4) 44.1 kWh** | | | | | | | | | |
| 7/20/2023 | 38.85 | 1.838 | 10145 | 2.998-3.175 | 4.132-4.153 | 84 | 93 | 95 | 95.83 |
| 12/17/2023 | 39.1 | 2.028 | 15030 | 2.971-3.147 | 4.131-4.151 | 136 | 145 | 95 | 95.40 |
| 3/23/2024 | 38.8 | 2.363 | 17426 | 2.992-3.168 | 4.130-4.152 | 168 | 307 | 94 | 94.64 |
| **Renault Zoe R90 (Zoe 2) 44.1 kWh** | | | | | | | | | |
| 7/20/2023 | 38.95 | 2.046 | 18020 | 3.012-3.232 | 4.124-4.142 | 221 | 418 | 95 | 95.36 |
| 12/20/2023 | 38.3 | 2.218 | 21472 | 3.032-3.250 | 4.122-4.139 | 259 | 626 | 94 | 94.97 |
| 3/26/2024 | 38.73 | 2.48 | 22872 | 2.997-3.245 | 4.117-4.133 | 274 | 737 | 94 | 94.38 |
| **Renault Zoe R90 (Zoe S) 44.1 kWh** | | | | | | | | | |
| 3/26/2024 | 37.85 | 3.04 | 58766 | 3.006-3.189 | 4.136-4.152 | 238 | 1537 | 92 | 93.11 |
| **Renault Zoe 20 (Zoe F) 25.9 kWh** | | | | | | | | | |
| 10/16/2023 | 20.3 | 4.56 | 101847 | 2.97 | 4.10 | 1496 | 2667 | 88 | 82.39 |
| 2/5/2024 | 20.15 | 4.6 | 106536 | 2.99 | 4.11 | 1515 | 2835 | 88 | 82.24 |

available EV battery types and a detailed investigation of the degradation of Renault Zoe R90 NMC batteries. Our extensive review of 50 commercial EV models revealed a predominance of NMC and LFP batteries, with evolving trends such as a shift towards reducing cobalt in NMC batteries from NMC532 to NMC811 and future applications of NMC955. The review highlights a possible preference for NCA batteries in high-end vehicles. Simultaneously, our empirical study on Renault Zoe models, using a noninvasive CANBUS measurement technique, shed light on the real-world degradation patterns of NMC batteries. Delving deeper into the results, we found that the three 2018 R90 models (Zoe2, Zoe4, and ZoeS), though identical in production, exhibited varied degradation levels attributed to different usage patterns. In particular, Zoe4, with the lowest kilometers driven, demonstrated the least degradation, serving as a benchmark for evaluating calendar aging. In contrast, Zoe2 and ZoeS, with higher usage, showed accelerated degradation, illustrating the impact of higher usage on battery health. Additionally, the older Q210 (2013) model (ZoeF) displayed a slower degradation rate, suggesting a diminishing impact of aging beyond a certain threshold.

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## REFERENCES

[1] F. Jung, M. Schröder, and M. Timme, "Exponential adoption of battery electric cars," *PLoS one*, vol. 18, no. 12, p. e0295692, 2023.

[2] X. Chen, W. Shen, T. T. Vo, Z. Cao, and A. Kapoor, "An Overview of Lithium-ion Batteries for Electric Vehicles," *2012 10th International Power & Energy Conference (IPEC)*, pp. 230–235, 2012.

[3] J. Duan, X. Tang, H. Dai, Y. Yang, W. Wu, X. Wei, and Y. Huang, *Building Safe Lithium - Ion Batteries for Electric Vehicles : A Review*, vol. 3. Springer Singapore, 2020.

[4] Y. Miao, P. Hynan, A. Von Jouanne, and A. Yokochi, "Current li-ion battery technologies in electric vehicles and opportunities for advancements," *Energies*, vol. 12, no. 6, p. 1074, 2019.

[5] Nicola Jones, "The new car batteries that could power the electric vehicle revolution," *Nature*, 2024.

[6] T. Kim, W. Song, D.-Y. Son, L. K. Ono, and Y. Qi, "Lithium-ion batteries: outlook on present, future, and hybridized technologies," *Journal of materials chemistry A*, vol. 7, no. 7, pp. 2942–2964, 2019.

[7] A. Barré, B. Deguilhem, S. Grolleau, M. Gérard, F. Suard, and D. Riu, "A review on lithium-ion battery ageing mechanisms and estimations for automotive applications," *Journal of power sources*, vol. 241, pp. 680–689, 2013.

[8] X. Han, L. Lu, Y. Zheng, X. Feng, Z. Li, J. Li, and M. Ouyang, "A review on the key issues of the lithium ion battery degradation among the whole life cycle," *eTransportation*, vol. 1, p. 100005, 2019.

[9] R. P. Ramasamy, R. E. White, and B. N. Popov, "Calendar life performance of pouch lithium-ion cells," *Journal of Power Sources*, vol. 141, no. 2, pp. 298–306, 2005.

[10] Z. Li, J. Huang, B. Y. Liaw, V. Metzler, and J. Zhang, "A review of lithium deposition in lithium-ion and lithium metal secondary batteries," *Journal of power sources*, vol. 254, pp. 168–182, 2014.

[11] A. Wang, S. Kadam, H. Li, S. Shi, and Y. Qi, "Review on modeling of the anode solid electrolyte interphase (sei) for lithium-ion batteries," *NPJ Computational materials*, vol. 4, no. 1, p. 15, 2018.

[12] R. Guo, L. Lu, M. Ouyang, and X. Feng, "Mechanism of the entire overdischarge process and overdischarge-induced internal short circuit in lithium-ion batteries," *Scientific reports*, vol. 6, no. 1, p. 30248, 2016.

[13] G. Fan, K. Pan, M. Canova, J. Marcicki, and X. G. Yang, "Modeling of li-ion cells for fast simulation of high c-rate and low temperature operations," *Journal of The Electrochemical Society*, vol. 163, no. 5, p. A666, 2016.

[14] Q. Wang, Z. Wang, P. Liu, L. Zhang, D. U. Sauer, and W. Li, "Large-scale field data-based battery aging prediction driven by statistical features and machine learning," *Cell Reports Physical Science*, vol. 4, no. 12, 2023.

[15] M. Marinelli, L. Calearo, J. Engelhardt, and G. Rohde, "Electrical thermal and degradation measurements of the leaf e-plus 62-kwh battery pack," in *2022 International Conference on Renewable Energies and Smart Technologies (REST)*, vol. 1, pp. 1–5, IEEE, 2022.

[16] B. Xu, S. Member, A. Oudalov, A. Ulbig, G. Andersson, and D. S. Kirschen, "Modeling of Lithium-Ion Battery Degradation for Cell Life Assessment," vol. 9, no. 2, pp. 1131–1140, 2018.

[17] M. Marinelli, L. Calearo, and J. Engelhardt, "A simplified electric vehicle battery degradation model validated with the nissan leaf e-plus 62-kwh," in *Proceedings of 6th International Electric Vehicle Technology Conference*, 2023.

[18] "Electric Vehicle Database," 2024.

[19] L. Calearo, A. Thingvad, C. Ziras, and M. Marinelli, "A methodology to model and validate electro-thermal-aging dynamics of electric vehicle battery packs," *Journal of energy storage*, vol. 55, p. 105538, 2022.

[20] K. Sevdari, L. Calearo, B. H. Bakken, P. B. Andersen, and M. Marinelli, "Experimental validation of onboard electric vehicle chargers to improve the efficiency of smart charging operation," *Sustainable Energy Technologies and Assessments*, vol. 60, no. September, p. 103512, 2023.

[21] M. Thingvad, L. Calearo, A. Thingvad, R. Viskinde, and M. Marinelli, "Characterization of nmc lithium-ion battery degradation for improved online state estimation," in *2020 55th International Universities Power Engineering Conference (UPEC)*, pp. 1–6, IEEE, 2020.