Environmental Test Validation of Nano EV Batteries

Ramaswamy Soundara Rajan, PhD (Part-Time)[1]
Research Scholar, Dept. of Electrical Engineering
University College of Engineering, Osmania University, Hyderabad, India

Prof. (Dr.) G. Yesuratnam, M. Tech, PhD (IISc.)[2]
Sr. Professor, Dept. of Electrical Engineering
University College of Engineering, Osmania University, Hyderabad, India

ABSTRACT

Ruggedized Electric Batteries made up of nano-additive based manufacturing process has subjected to very severe environmental stress and strain condition for better operational performance and longtime durability. To withstand harsh environment condition like extreme hot and cold temperature, shock, vibration, high altitude and damp heat condition, the EV batteries to be tested with stringent environmental testing standards for high performance validation and qualification. This aims to study, simulate and analyses such environmental stresses and ageing effect on nano electric batteries for high performance all weather and all terrain road testing condition. To simulate climatic and dynamic environmental conditions of nano electric battery performances are compared and presented. This research paper also focuses on the performance prediction of the stored nano batteries in the field for specific operational condition and extrapolate for the desired test results.

Keywords *– Nano-additives, ESS, Stress, Climatic, Dynamic, Thermal Cycle, Random Vibration.*

1.0 Introduction

The projected sales of Electric Vehicles (EV) is exponentially increased from 3.4% in 2021 to 29.5% in year 2030 with on an average of 4.7 million Evs on road per year. New technology, emissions regulations, environmental considerations, cost, and rapidly changing market as key elements toward abandoning petroleum vehicles. As demand increases, manufacturers are eyeing advancements in battery technology to make EVs more accessible, economical, and longer-lasting.

Unlike internal combustion engines, EVs rely on an electric traction motor powered by an onboard electric battery pack. The traction battery pack which drives the motor must be rechargeable, and the race continues to develop lighter, longer-lasting and more efficiently charged battery packs.

Some battery manufacturers today are introducing paradigm shifts in battery charging capacities, with one company demonstrating a proof of concept battery that powered an EV 752 miles without recharging. While this type of extended range relies on dual-energy chemistry, there largely remain four types of battery technology used in EVs today.

Environmental testing is important to ensure that batteries can perform under extreme conditions. It can also help to identify potential problems and improve the safety and reliability of the batteries. Environmental testing for electric vehicle (EV) batteries simulates extreme conditions to ensure they can perform and withstand them. These tests can include but not limited to temperature and humidity. Vibration and shock: Batteries are tested for vibrations and shock under different climatic conditions. Altitude: Batteries are tested for altitude simulation. Corrosion: Batteries are tested for corrosion, such as salt spray. Water immersion: Batteries are tested for immersion splash water. Electromagnetic compatibility: Batteries are tested for electromagnetic compatibility. Chemical influence: Batteries are tested for chemical influence. Thermal cycling: Batteries are tested for thermal cycling.

2.0 Components of Electric Vehicles

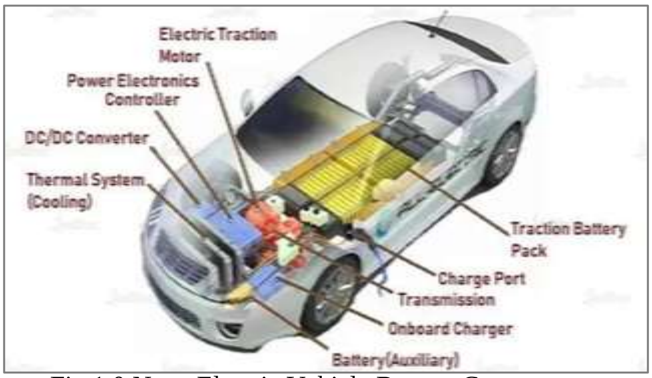


Fig 1.0 Nano Electric Vehicle Battery Components

2.1 Battery Pack

A battery is a device that retains electric charges. Anode, which is negatively charged, and cathode, which is positively charged, end up making up a battery. Because there has been an immoderate accumulation of electrons, which already have a negative charge, the anode is negatively charged. In contrast, a lack of electrons causes the cathode to be positively charged. But the basic workings of an EV battery pack are similar to those of a standard battery. The Electric Vehicle battery pack's anode and cathode work in concert to produce power at the most fundamental level within each battery cell.

2.2 Electric Motor

The real power behind electric cars is provided by electric motors (EVs). The electric motor, together with the batteries and power electronics, is a crucial part of the electric vehicle. Radial flux is used throughout the whole EV market. But these days, several electric vehicle manufacturers, like Tesla, have begun to employ axial flux motor technology because of its many advantages, including higher engine power and increased torque density.

2.3 DC-DC Converter

The fundamental purpose of DC/DC converters is the same regardless of the model upon which they are built. A step-up converter transforms a low-voltage input into a high-voltage output, whereas a step-down converter does the exact reverse. An electric vehicle's batteries generally produce a DC voltage of several hundred volts. The voltage requirements for the electric parts within the car vary, albeit most of them operate at significantly lower voltages. A steady voltage is provided by the traction battery pack. But the criteria for various vehicle components vary. The battery's output power is dispersed to the necessary level by the DC-DC converter. Additionally, it supplies the power needed to recharge the backup battery.

2.4 Charger Port

The electric car is connected to an external source through the charging connector. The battery pack is being charged. The vehicle's front or back may occasionally hold charging port.

2.5 Transmission

The transmission is not necessary for electric motors.
Electric cars use a direct transmission system as opposed to the multi-speed transmissions seen in cars powered by fossil fuels. Electric vehicles employ drive mode selectors instead of standard transmission systems, which are less complicated and have fewer movable parts than conventional gearboxes.

Fig 2.0 Nano Electric Vehicle Battery Experimental Setup

2.6 Controller

The controller's primary role is to monitor how much power is sent to the electric motors from the battery and inverter. Controller receives the majority of its feedback from the vehicle's accelerator pedal (which is set by the driver). Additionally, the accelerator pedal regulates the voltage or frequency variations that feed the motor and increases the electric vehicle's pace.

2.7 Thermal-System Cooling

This device ensures that the engine, electric motor, power systems, and other parts run within ideal temperature zone.

2.8 Power Control Unit

The power control unit is a crucial component that transforms DC power generated by the battery back into AC power, which the majority of electric motors need. An inverter, a part used to power computers or other equipment utilizing a 12-volt plug in the vehicle's dash, is utilized to finish this operation. The drivetrain is connected to the accelerator, start button, and drive mode controller via a power control unit. Additionally, it controls regenerative, which is how an EV sends energy back to the battery system when slowing

3.0 Performance Testing Standards of EV Battery

New Chroma Battery Pack Integrated Test bed for EV Composite. EV battery testing is important to ensure that batteries are safe and meet the manufacturer's performance specs. The standards for testing EV batteries, including:

AIS-156 and AIS-038 (Rev 2): These Automotive Industry Standards (AIS) were amended in October 2022 to strengthen safety parameters for EV battery testing.

IS 17855: 2022: This standard covers the performance, reliability, and electrical functionality of battery packs and systems for EVs. It includes tests for real-life scenarios, such as low and high temperatures, and when the battery is not used for a long time.

IEC 62660-2 (2018): This standard defines tests for the reliability and abuse of lithium-ion batteries used in EVs. Tests includes vibration, shock, crush, high-temperature endurance & electrical short circuit.

SAE J2564: This standard is considered a benchmark for abuse testing batteries, capacitors in EVs and hybrid vehicles.

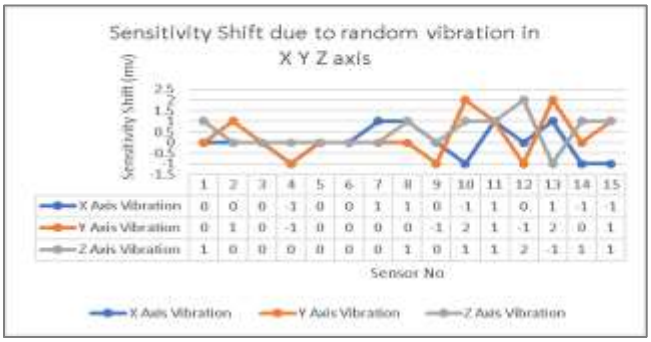
IEC 62133: This standard covers various aspects of battery safety, including electrical, mechanical, and chemical safety.

ISO 12405: This standard is a test specification for lithium-ion traction battery packs and systems.

ISO 16750: This standard applies to EV systems and components, and focuses on potential environmental stresses.

UL 2271: This standard covers the safety requirements for designing, manufacturing, and testing lithium-ion batteries used in small platforms, such as e-bikes and scooters.

4.0 Random Vibration Test of EV Battery:



Graph 1. (a) Random vibration results for sensitivity drift

Graph 1. (b) Random vibration results for zero drift

The sensitivity drift and zero drift are the two important mission critical performance parameters of the Nano Battery and sensitive to various type of stresses experienced during storage and transportation. The sensitivity drift also known as scale factor drift, defines the amount by which EV battery sensitivity varies as environmental conditions change. The zero drift or bias describes the effect where the zero reading of a battery is shifted by a change in environmental condition.

5.0 Methodology for Environmental Stress Simulation.

In practice many types of performance prediction tests are conducted either for checking operational requirements or storage / transportation (non-operational) requirement. During storage and transportation of EV batteries, various dynamic and climatic environmental factors are associated which can be simulated in the test lab in reference to MIL standard 810H and the performance of the EV batteries can be analysed. These tests give the results similar to the actual operational conditions but not the same. This paper is about the experimental studies which is carried out on 15 Nos of 12 Volts range Nano Batteries from 3 different batches and 5 samples from each batch to know the dominating stresses and the probable drift in the sensitivity and zero due to dynamic and climatic environmental factors.

6.0 Dynamic Environmental Test and Results

6.1 Random Vibration: These are the oscillations of mechanical systems excited by environments that vary randomly in time. Experimental studies of random vibrations are carried out to predict the characteristics of system responses, to demonstrate the survivability of physical systems. To simulate the random vibration in laboratory, the electrodynamic vibration shaker is used and the EV battery under tests are mounted on the vibration table with the help of suitable fixture to simulate the dynamic environment and the vibration tests carried out in Pitch, Yaw and Longitudinal axis as per the MIL standard 810H specification listed in table1.0 and the test results are summarised in Fig 2 (a) and (b) for the sensitivity and zero drift of the Nano Battery.

Table 1.0 Vibrational Test Specifications

20 Hz to 100 Hz	+6 dB/Octave
100 Hz to 1000 Hz	0.045 g2/Hz
1000 Hz to 2000Hz	-6dB/Octave
Duration	180 Sec
Axis	X, Y, Z

From Fig 2(a), it is observed that the maximum sensitivity drift is 2mv in Yaw (Y Axis) and longitudinal axis (Z Axis)

From Fig (2) b, it is observed that the maximum zero drift is 2 mv in all three axis. In random vibration sensitivity and zero drift is 2mv equivalent to 0.00625 Volts, which is almost negligible shift.

7.0 Climatic Test and Results

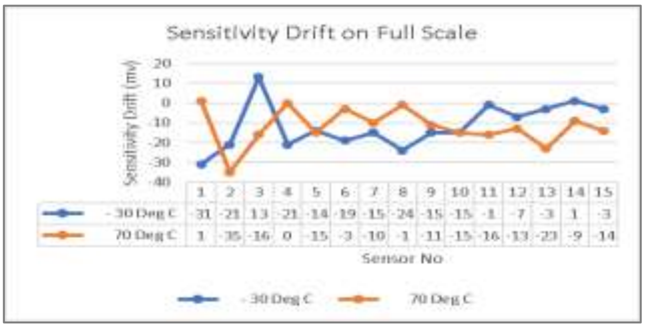
7.1 Thermal Cyclic Test

The objective of the thermal cycling testing is to determine the ability of parts and solder interconnects to resist extremely high and low temperatures, as well as their ability to endure cyclical exposures to extreme temperatures during storage of the systems during the life cycle (4).

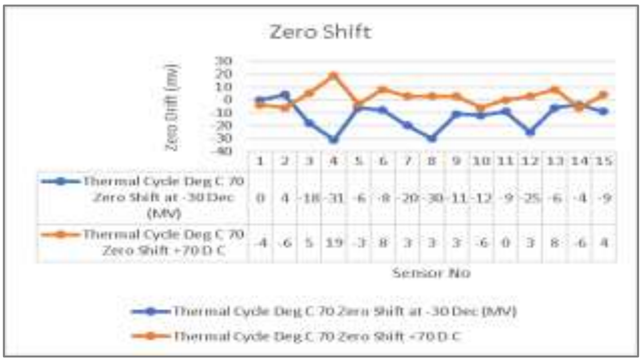
Thermal cyclic test carried out in a temperature chamber as per the MIL standard specification 810H listed in table 2 to simulate the thermal stresses due to climatic storage condition for the Nano Battery and the test results are summarised in Fig 3 (a) and (b).

Table 2.0 Thermal Chamber Specifications

Thermal Cycling	-30 Deg C to +70 Deg C
Dwell Time	1 Hrs, Temp10 Deg C/Min
No of Cycles	6



Graph 2. (a) Thermal cyclic results for sensitivity drift



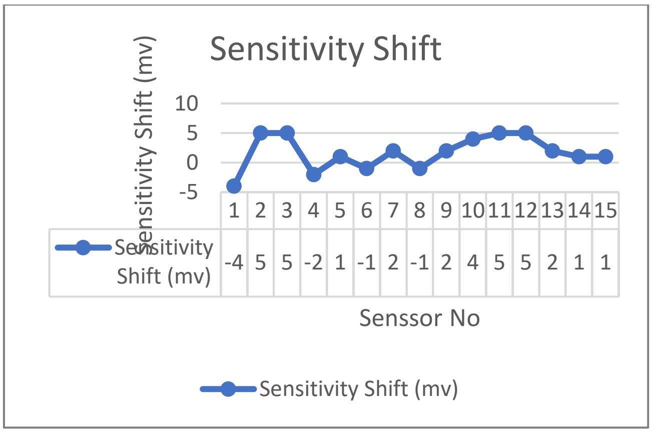
Graph 2. (b) Thermal cyclic results for zero drift

From fig 3(a) it is observed that the sensitivity drift is random at Temperature range -30 deg c to + 70 deg C and maximum drift is -35 mv on full range of the sensor, similarly from fig 3(b) it is observed that the maximum zero drift is -31 mv . In both the cases the drift is almost equivalent to 1.0 volt.

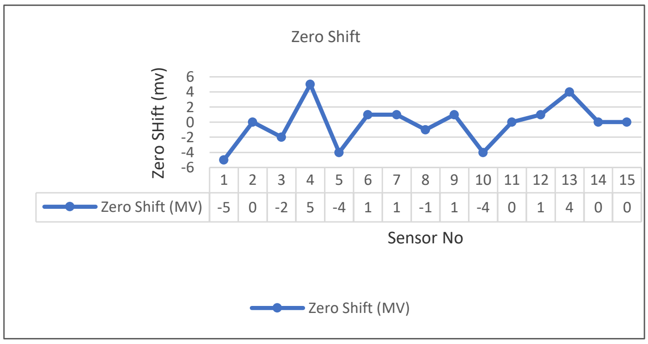
7.2 Damp Heat Test

This test carried out in damp heat chamber to simulate the stress due to high humid environmental condition during storage EV batteries as well as the effect of it on integrated battery performance. Tests carried out on 15 numbers of 150 volt Nano Battery at +45 Deg C, 95% RH for 8 Hrs. as per MIL standard 810H and results are summarized in fig 4(a) and (b) for sensitivity and zero drift.

From fig 4(a) it is observed that the sensitivity drift is random and maximum drift is 5 mV on full range of the sensor, similarly from fig 4(b) it is observed that the maximum zero drift is -5 mV. In both the cases the drift is equivalent to 0.00964 volts which almost negligible with respect to measurement range



Graph 3. (a) Sensitivity drift due to damp heat stress



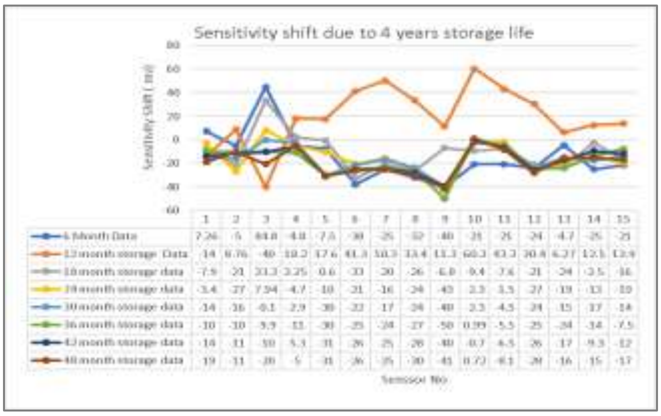
Graph 3. (b) Zero drift due to damp heat stress

8.0 Methodology for Laboratory Stress Simulation Test Result Validation.

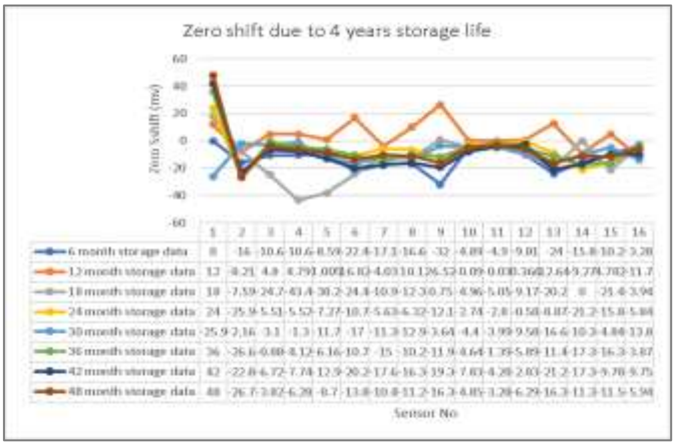
Field data of 30 numbers of battery collected from geographically dispersed storage locations of the weapon systems during periodical health monitoring of stored weapon system. This data is used to validate the Nano Battery performance test results obtained during the laboratory simulations of the storage environmental stress conditions and to know the combined effect of ageing and storage environmental stress conditions on the performance of battery during storage of weapon system.

During Storage of the weapon system the storage temperature was in between from -10 Deg C to +45 Deg C. The frequency of data collection is six monthly from the date of storage up to 48 months (4years) to know the trends in performance deviation due to combined effect of the 4 years storage age and environmental storage conditions mainly the thermal stress and it is assumed that the effect of other stresses like vibration, shock and humidity are negligible as the similar results were observed during the laboratory stress simulation in para 4 and 5.

At the time of data collection, the weapon system storage temperature was at 25 ±2 Deg C. Results were analysed for every six-month data up to 48 months (4 years) from the day of storage for the sensitivity and zero drift in 15 numbers of weapon integrated Nano Battery stored in environmental condition as shown in fig 5(a) and 5(b)



Graph 4. (a). Sensitivity drift due to 4 years storage environmental condition.



Graph 4. (b). Zero drift due to 4 years storage environmental condition.

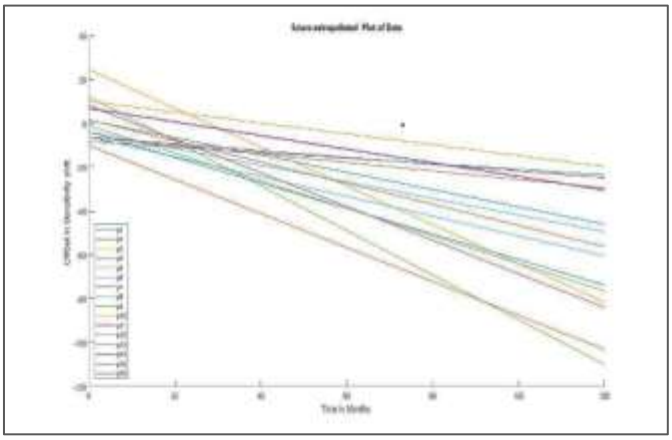
The maximum sensitivity drift observed is ±61 mv and zero drift is ±41 mV, which indicate that combined effect of 4 years storage environmental condition mainly thermal stress and ageing on the Nano Battery performance in terms of Nano Battery sensitivity and zero drift is approximately 3.5 volts and 2 volts respectively. During laboratory test the maximum drift in sensitivity and zero observed was ±1 volts due to the thermal stress while the effect of the vibration, shock and humidity stresses were negligible.

9.0 Data Extrapolation for 10 Years Storage

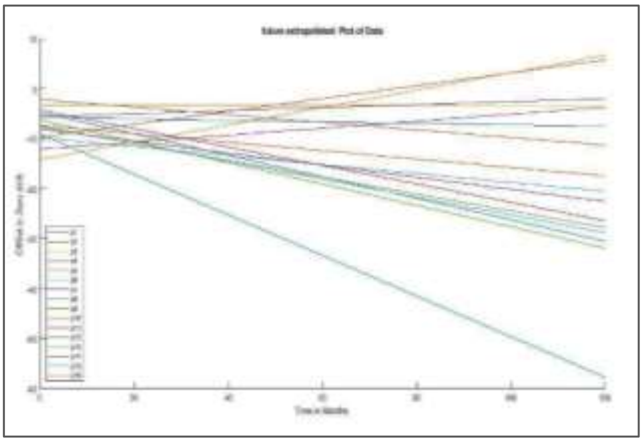
Data collected for 30 numbers of Nano Battery integrated in weapon systems stored since 4 years and predicted the Nano Battery performance in terms of zero and sensitivity drift respectively up to 10-years (120 months) storage life using the linear regression analysis and Polyfit function of the MATLAB.

9.1 Sensitivity drift prediction:

For sensitivity drift prediction, the data of 15 numbers of Nano Battery with 4 years storage life analysed and polynomial graphs plotted using polyfit function of the MATLAB as shown Fig 6 (a). The two variables for linear extrapolation are storage time and drift in sensitivity.



Graph 5. **(a)** Prediction of Sensitivity drift due to storage environmental condition and 10 years storage life.



Graph 5. **(b)** prediction of zero drift due to storage environmental condition and 10 years storage life.

The polynomial equations for every Nano Battery derived and the best suitable equation finalized based on the R-squared value for the prediction of sensitivity drift. The R-squared is the coefficient of the determination and ranges from 0 to 1

$$\textbf{Sensitivity drift} \quad = \frac{85291}{7000} - \frac{(4582046256594079*x)}{4503599627370496}$$

R- Squared value = 0.7, which is the best suited for sensitivity drift prediction among all 15 sensors R-squared value. In above equation ‘x’ is the time period variable.

The max sensitivity drift observed for 10-year storage is +5 mV to -100 mV which is approx. to maximum 3.5 V

9.2 Zero drift prediction:

For zero drift prediction, 15 numbers of Nano Battery data analysed and polynomial graph plotted as shown in graph 6(b), for 10 years (120 months) life prediction in terms of Nano Battery zero drift. The best suited polynomial equation derived using MATLAB polyfit function for the prediction for which the R-squared value is 0.6.

$$\textbf{Zero drift} = \frac{(22759*x)}{56000} - \frac{2532088574422623}{281474976710656}$$

The maximum zero drift estimated for 10-years is +10 mV to -60 mV which is equivalent to approximately 2.0 volts as shown in Fig 6 (b).For the prediction of 10-years storage Nano Battery performance in terms of sensitivity and zero drift, it is considered that temperature is between -10 deg C to +45 deg C at geographically dispersed storage locations and effect of other stresses like vibration, shock and humidity are negligible.

The 10-years prediction of the sensitivity and zero drift starting from 5th year to 10th year are summarised in the table 3 and results are indicating that for 10 years storage life of weapon systems the drift in sensitivity and zero are within the specified limit of Nano Battery to perform as desire.

Table 3.0 Performance Prediction for 10 years

Year ⟶	5th	6th	7th	8th	9th	10th
Sensitivity	-48.	-61	- 73.2	- 85.4	- 97.6	- 109
Zero	-33.3	-38.2	- 43.1	- 44.0	- 52.8	-57

10.0 Conclusion

Environmental testing for electric vehicle (EV) batteries helps determine their performance and health. It can also help identify challenges and opportunities for improving the environmental impact of EVs. We have highlighted some of Efficiency testing: Measures the battery's output voltage and current to determine how effectively it converts stored energy into electrical energy. Cycling testing: subjects the battery to a series of charge and discharge cycles to determine how long it can be used over its lifetime. Temperature testing: Exposes the battery to different heat ranges to determine its performance under various conditions. Aging testing: Subjects the battery to a series of charge and discharge cycles over an extended period to determine its performance over time: Cell formation testing: Conditions new batteries to ensure they perform at their best before being put into service.

Some environmental challenges associated with EVs include: Battery production: The mining, processing, and manufacturing stages of battery production contribute to a significant portion of the overall emissions linked to EVs.
Battery recycling: Only 5% of the world's total batteries are currently recycled, mainly due to cost and the long process required. Metal extraction: The extraction of metals like nickel and cobalt for EV batteries can have hazardous environmental impacts.

Some potential solutions to these challenges include: Improving battery technology to reduce charging times and address range anxiety, Enhancing the charging infrastructure, Increasing the number of charging stations, Using battery swapping techniques, and Recycling and reusing batteries.

11.0 References:

[1] Predictive Reliability of Tactical Missiles using health monitoring data and probabilistic engineering analysis., Stephen A. Marotta, US Army, Aviation and Missile Research Development and Engineering Center (AMRDEC), Presenter Abdul Kudiya, US Army AMRDEC Teng K. Ooi, US Army AMRDEC Houssam A. Toutanji, University of Alabama in Huntsville John A. Gilbert, University of Alabama in Huntsville

[2] Guo, J.; Li, Y.; Pedersen, K.; Stroe, D.-I. Lithium-Ion Battery Operation, Degradation, Aging Mechanism in EVs: An Overview. Energies 2021, 14, 5220.

[3] Martín, I.S.; Braco, E.; Martin, Á.; Sanchis, P.; Ursúa, A. Integration of Second-Life Batteries in Residential Microgrids and Fast Charging Stations. In Proceedings of the 2022 IEEE International Conference on Environment and Electrical Engineering and 2022 IEEE Industrial and Commercial Power Systems Europe (EEEIC/I&CPS Europe), Prague, Czech Republic, 28 June–1 July 2022; pp. 1–6.

[4] Ecker, M.; Gerschler, J.B.; Vogel, J.; Käbitz, S.; Hust, F.; Dechent, P.; Sauer, D.U. Development of a Lifetime Prediction Model for Lithium-Ion Batteries Based on Extended Accelerated Aging Test Data. J. Power Sources 2012, 215, 248–257

[5] Micari, S.; Foti, S.; Testa, A.; De Caro, S.; Sergi, F.; Andaloro, L.; Aloisio, D.; Leonardi, S.G.; Napoli, G. Effect of WLTP CLASS 3B Driving Cycle on Lithium-Ion Battery Electric Vehicles. Energies 2022, 15, 6703.

[6] Cicconi, P.; Landi, D.; Morbidoni, A.; Germani, M. Feasibility Analysis of Second Life Applications for Li-Ion Cells Used in Electric Powertrain Using Environmental Indicators. In Proceedings of the 2012 IEEE International Energy Conference and Exhibition (ENERGYCON), Florence, Italy, 9–12 September 2012; pp. 985–990.

[7] M. Hooper, J. Marco Characterising the in-vehicle vibration inputs to the high voltage battery of an electric vehicle J. Power Sources (245) (2014), pp. 510-519.

[8] G. Kjell, J.F. Lang Comparing different vibration tests proposed for li-ion batteries with vibration measurement in an electric vehicle EVS27 International Battery, Hybrid and Fuel Cell Electric Vehicle Symposium, Barcelona, Spain (2013), pp. 1-11.

[9] Influences on vibration load testing levels for BEV automotive battery packs T Heinzen, B Plaumann, M Kaatz - Vehicles, 2023 - mdpi.com.

[10] A review of lithium-ion battery failure hazards: Test standards, accident analysis, and safety suggestions X Lai, J Yao, C Jin, X Feng, H Wang, C Xu, Y Zheng - Batteries, 2022 - mdpi.com.

[11] Characterization of in-situ material properties of pouch lithium-ion batteries in tension from three-point bending tests MM Keshavarzi, M Gilaki, E Sahraei - International Journal of Mechanical, 2022 – Elsevier.

[12] Experimental and modeling approaches for electric vehicle battery safety: a technical review T Long, L Wang, CD Kan - Engineering Research Express, 2024 - iopscience.iop.org.

[13] Battery crush test procedures in standards and regulation: Need augmentation harmonization B Kotak, Y Kotak, K Brade, T Kubjatko, HG Schweiger - Batteries, 2021.

[14] The evolution of thermal runaway parameters of lithium-ion batteries under different abuse conditions: A review B Nie, Y Dong, L Chang - Journal of Energy Storage, 2024 - Elsevier

Authors Profile

[1] **Ramaswamy Soundara Rajan, PhD (Part Time)** Research Scholar in Electrical & Electronics Engineering University College of Engineering, Osmania University Hyderabad, Telangana State, India. His research area are Power Electronics Controllers, Nano Technology based Electric Batteries, Energy Storage Systems, Aerospace & Defense Systems Integration, Assembly and Testing, working as Sr. DGM (Strategic Defence Project) BDL

Email: rsrajan2006@gmail.com

[2] **Prof.(Dr) G. Yesuratnam, M. Tech, PhD (IISc)** Senior Professor in Department of Electrical & Electronics Engineering, University College of Engineering, Osmania University Hyderabad, Telangana State, India. Specialized in Computer aided power system analysis, Reactive power optimization, Power system security, Voltage stability, AI based applications in power systems and Gas Insulated Substations. Published number of papers in national and international conferences and Journals. Served various prominent positions in Osmania University.

Email: ratnamgy2003@gmail.com