International Journal of Reliability and Applications
Vol. 12, No. 2, pp. 123-129, 2011

Study of electric vehicle battery reliability improvement

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Abstract. Due to restriction of vehicle emissions and high demand for fossil fuels nowadays, car manufacturers around the world are looking into alternative ways in introducing new car model that would vastly captured the market. Thus, Electric Vehicle (EV) has been further developed to take the advantage of the current global issues on price of fossil fuels and impact on the environment. Since car battery plays the crucial role on the overall performance of EV, many researchers have been working on improving the component. This paper focused on the reliability of EV battery which involves recognizing failure types, testing method and life prediction method. By focusing on these elements, the reliability feature being identified and as a result the batteries life will be prolonged.

Key Words: *Electric vehicle battery, reliability improvement*

1. INTRODUCTION

EV model has its own type of battery such as advanced Pb-acid, NiMH or Li-ion as a source of power for the vehicle to move thus it is considered as vital component. The potential expansion of EV industry has made the enhancement of battery technology becomes crucial due to its application. The major drawback of EV battery that prevents the car manufacturers to vastly produce EV to the market is maintaining performance and dependability of the battery without failure for a specified period of time. Chan (2007) has mentioned that high initial cost, short driving range, long charging time, and reduced passenger and cargo space have portrayed the limitation of battery-powered EVs.

Features of ideal EV battery must have enough power to be attained for long range with one charge and provide stable acceleration and ascending power capability. The battery with high safety mechanism, free maintenance and recyclable would make it the perfect car to be owned by the customer. Therefore, the reliability of EV batteries is

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important when the car manufacturer decided to introduce EV widely to the customers. Based on Tollefson (2008) article, battery technology is mostly associated as EV technical barrier.

The first step to understand the reliability of EV batteries is to recognize the types of failures that occurred. After the failure types have been identified and investigated, appropriate testing methods are used in order to ensure the performance of the batteries are up to the expectation and to detect any design deficiencies. It also helps to ensure the safety of the batteries comply with government regulations for public use. Life time prediction model is also important in improving the reliability of the batteries.

2. BATTERY FAILURE TYPES

Possible failure modes of EV battery can be categories as battery operating conditions and also chemical process. Battery operating conditions failures, which cover charging/discharging depth, high/low temperature and vibration, are grid corrosion, grid growth and discharging of negative plate. Salloux and Mc Hardy (2007) have discussed that dry-out and sulfation are common failures in chemical process in their research on Valve Regulated Lead Acid (VRLA) battery.

The leading cause of battery failure is grid corrosion in which the life expectancy of the battery is limited due to corrosion of the positive grid. As the battery cycles and ages, the conductivity of the grid is gradually reduced in which the material corrodes from the plate and accumulates at the bottom of the cell container. This accumulation of the material develops a conductive path and reduces the capacity of the cell. The rate of the corrosion grid can be reduced by applying low porosity thicker grids manufactured using bottom-pour casting.

Grid growth is the common premature battery failure due to crack of the battery container especially at weakest link which is the terminal posts. The plates grow in size during the battery life in which puts pressure from within the container. The current design of the battery which integrates extra space to have room for the expansion could overcome this phenomenon. Discharging of the negative plate over a period of time is another common failure. Negative plate take in oxygen release by positive plate during charging process in which prevents the negative plate to reach fully charged state. A catalyst that recombines the oxygen and the hydrogen has been introduced in new battery design which reduces oxygen diffusing at negative plate. As a result, negative plate will be maintained at full state of charge.

Dry-out is occurred due to extensive overcharging or overheating of the battery which leads to water lost from the cell and the separator loses conductivity. This condition will shorten the life of the battery. By adding catalyst that recombines the oxygen and the hydrogen, it will help to recover water lost and prevent dry-out. Sulfation takes place when the lead sulphate crystals formed and gradually build up and fail to re-dissolve back to active material during charging. This will reduce the capacity of the battery. Moseley and Rand (2004) have studied on VRLA batteries that are plagued by a tendency to accumulate sulphate on the negative plate. To counter this problem, appropriate design of the plate grid can enhance the ability of the battery to improve.

Table 3.1. Lists of tests in USABC test procedures manual

Core Battery Performance Test	Constant current discharge	To determine the sustained (30s) discharge power capability of a battery at 2/3 of its open circuit voltage at each of various depths of discharge.
	Peak power	To perform a sequence of constant power discharge/ charge cycles that define the voltage versus power behaviour of a battery as a function of depth of discharge.
	Variable power discharge	To produce the effects of electric vehicle driving behaviour (including regenerative braking) on the performance and life of a battery.
	Federal Urban Driving Schedule (FUDS) regime	It is a demanding profile with respect to the frequency of occurrence of high power peaks and ratio of maximum regenerative charging to discharge power.
	Dynamic stress test regime	Can effectively simulate dynamic discharging and can be implemented with equipment at most test laboratories and developers.
Special Performance Test	Partial discharge, Stand loss, Sustained hill-climb power, Thermal performance, Battery vibration, fast charging	
Safety and Abuse Test	Safety testing	To address conditions associated with government regulations or expected accident-related exposures
	Abuse testing	Based on mechanical, electrical and environmental exposure for worse-case scenarios
Life Cycle Test	Accelerated aging	To accelerate relevant failure modes and degradation mechanisms to permit rationally precise aging factors to be determined.
	Actual-use simulation	To simulate the conditions that EV battery may experience in the actual operation and the result from these tests will validate the accelerated life-cycle test performed.
	Baseline life test	To determine the battery life achieved under a ‘reference’ or baseline set of test conditions, for comparison with the results of accelerated life testing under any other set of test conditions.

3. BATTERY TESTING METHOD

United States Advanced Battery Consortiums (USABC) has developed EV battery test procedures manual (second revision) dated on January 1996 in which summarizes the procedural information needed to perform the battery testing. USABC has been formed by the U.S. Department of Energy (DOE) to develop EV advanced batteries. The aim is to develop EV that is competitive with conventional IC engine vehicles in terms of performance and price.

Based on USBC EV battery test procedures manual, typical battery test flow includes the following areas which are core battery performance test, special performance testing, safety and abuse test, and life cycle testing. Core battery performance testing consists of mandatory electrical performance tests. Special performance testing is optional depends on the requirements of the manufacturer.

Safety and abuse testing is to make sure the systems are safe for customers and comply with government regulations. It also discovers any design deficiencies that may jeopardize the safety of the public.

Standard procedures are used in life cycle testing to determine if the expected service life of EV batteries will satisfy USABC requirements. Accelerated aging and normal use conditions are used to characterize degradation in electrical performance as a function of life and to identify relevant failure mechanisms. Table 3.1 shows details of the tests that are applied by USABC for battery testing.

Some other researches also propose battery testing methods specifically for certain type of battery for EV. Poscoe and Anbuky (2003) have developed the architecture of an automated battery test system which was designed for VRLA battery behavioural research with three most significant battery parameters: voltage, current and temperature. This testing technique comprises quality assurance, design verification and performance assessment purposes for battery manufacturers, validation purposes for battery users, and battery behavioural research purposes for engineers developing behavioural prediction algorithms.

4. LIFE PREDICTION METHOD

Lifetime prediction of batteries is widely discussed by researches around the world. Some of the battery lifetime prediction model proposed by the researches based on type of batteries and parameters.

Rahmatov and Virudhula (2001) have come up with analytical expression to estimate battery lifetime for various time-varying loads by taking into accounts the changes in the concentration of the electro active materials inside the battery. Sauer and Wenzl (2007) have discussed three different approaches for lifetime prediction for VRLA batteries which are physico-chemical ageing model, weight Ah ageing model and event-oriented ageing model. Then these three approaches are compared between parameter identification, model complexity and calculation speed. Marano et al (2009) have used different approaches for lifetime estimation of Li-ion battery which are performance-based models and weighted Ah-throughput model. Performance base models simulate the change of performance values of the battery. Agarwal et al (2010) have developed a nonchemically based partially linearized input-output battery model for lead-acid batteries. This model can be extended to different types of batteries if the parameters are properly tuned.

5. WAYS OF IMPROVEMENT

The reliability of the battery can be improved by integrating these criteria into the design of the battery which must perform their functions as expected (Lukic and Emadi, 2008).

5.1. Thermal protection

Both charge capacity and life cycle can be optimized when the battery is kept within a recommended operating temperature range between + 20°C to +30°C. Therefore to keep the temperature within that range, the system may need both heating and cooling elements to get optimal performance. If the temperature is too high or too low, it can cause poor performance and finally failure to the batteries. Jarrett and Kim (2011) have written a research paper on design optimization of EV battery cooling plates for thermal performance which help in temperature control.

5.2. SoC, SoH, monitoring

The accurate indication of how much longer a battery will continue to perform before it needs recharging would help the user to know the amount of energy left and to plan it out efficiently. State of Charge (SOC) estimation is often called the "Gas Gauge" or "Fuel Gauge" function which has the same function as a fuel tank in a car. Wang et al (2007) have pointed that the key factor for managing batteries efficiently is the accurate estimation of the SOC of the battery pack. State of Health (SOH) is measurement of battery ability to store energy, source and sink high currents, and retain charge over extended periods. This information is useful to ensure the battery operates within required safe limits and identifies any weak part for placement, other than carry out the regular maintenance.

5.3. Cell equalization (balancing) on cell

EV batteries consist of long strings of cells in series in order to achieve higher operating voltage. Equalization is used to prevent large long term unbalance rather than small short term deviations. It is also help to protect the cell from overstress. By using balancing method in which charge from one or more high cells are removed to lower charge cells will help to reduce the cells from overstress.

5.4. Tolerance setting

Premature failure of the battery can cause by over stress of individual cells in a series due to uneven temperature distribution and difference in aging. The best way is to select cells from the same manufacturing batch to minimize variability of traits in a group. If there are some degraded cells in the chain with diminished capacity, there are tendency to over charging the battery. The reliability of a battery will be improved with tight tolerance and strict process control.

Other improvement that could be made on the EV battery also have been highlighted in which related to battery management systems. Meissner and Richter (2005) have discussed that further technical improvement of EV batteries and procedures are needed for optimum use of the batteries resources, i.e., knowledge of actual SOC, power capability, and quantification of the degradation of the batteries performance as an input for energy management. Karden et al (2005) have mentioned that battery monitoring systems allow for more efficiently and effectively battery operating strategies which will improve the reliability of the battery in EV.

6. CONCLUSION

Reliability of the EV battery can be improved by understanding the failures occurred, types of testing conducted and method of prediction lifetime. Using the proposed approaches, the reliability of EV battery systems or components can meet the expectation values and also capable of prolong the battery life where as the battery selection depends on the application requirement. On the other hand, field data, usage and environmental profile are important in further improving the reliability of the EV battery. Unfortunately, EV car manufacturers hardly discuss on the current issues on problem occurred regarding the reliability of the battery.

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