Design and Development of Accelerated Life Tester for Qualification of Batteries

Syed Muhammad Arsalan Bashir[a], Syed Kazim Hasan Zaidi[b], and Muhammad Zaheer[c]

***Abstract*—Accelerated life testing (ALT) of batteries is performed to estimate the number of life cycles a battery can withstand in any mission fulfilling the mission power requirements. This test is destructive; therefore the battery cycles are exhausted completely. For ALT, selective samples are used to qualify the whole lot. Life of any space mission is dictated by batteries used in the mission, therefore the qualification process of batteries is quite critical.**

The present paper elaborates the design and development of Accelerated Life Tester for batteries (all types) according to the requirements of the Society of Automotive Engineer (SAE) standards. The setup is able to perform both charge and discharge cycles simultaneously with programmable cutoff voltage and current limits. Dedicated data acquisition system (DAQ) is developed in LabView that is capable of receiving data at high rates. Different sensors are used to monitor and control the test. The recorded data include body temperature of batteries, terminal voltages and current drawn. The real time data is stored in the LabView data file for post processing and at the same time it is shown as real time graphs for monitoring the test through a graphical user interface (GUI). Qualification of batteries is performed on selected samples in extreme test conditions, including high temperature, a high discharge rate and a high depth of discharge (DOD). The present setup provides these test conditions for performing ALT of batteries. The GUI controls every function of the test centrally, from test initiation to test termination that makes the test setup fully automated.

***Keywords*—accelerated life test; cycle life tester; accelerated life test for batteries; cycle life tester.**

I. Introduction

Accelerated life testing is of immense importance in predicting the life of an electrical component in a system. For power sources like batteries, accelerated life testing is vital for predicting the useful functional life of batteries. In this paper, we are presenting the design and development of an accelerated life tester for batteries, which will analyze the charge-discharge cycle of batteries. Major parameters (including charge/discharge rate, cutoff voltages, temperature thresholds, etc.) are soft programmed, and can be set according to the specification sheet of the battery under test.

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[a]Assistant Manager, QA Electronics Dte, QA Electronics Division, Quality Management Directorate General. Pakistan Space and Upper Atmosphere Research Commission (SUPARCO), 75270 Karachi, Pakistan. Email: smab1176@yahoo.com. Tel.: +92-345-2252898; fax: +92-21-32593223.

[b]Manager, QA Electronics Dte, QA Electronics Division, Quality Management Directorate General. Pakistan Space and Upper Atmosphere Research Commission (SUPARCO), 75270 Karachi, Pakistan. Email: zkashmiri@hotmail.com. Tel.: +92-321-3626268; fax: +92-21-32593223.

[c]Manager, QA Electronics Dte, QA Electronics Division, Quality Management Directorate General. Pakistan Space and Upper Atmosphere Research Commission (SUPARCO), 75270 Karachi, Pakistan. Email: zkashmiri@hotmail.com. Tel.: +92-321-3626268; fax: +92-21-32593223.

This test determines the number of life cycles a battery will survive. This test is destructive as the battery cycles are exhausted completely and hence the batteries cannot be used after ALT completely so selective samples may be used to qualify the whole lot.

In [1], operating temperature, charge rate and discharge rate are the main factors that define the degradation in the efficiency of high capacity batteries. In our design criteria, the critical test parameters are same as discussed in [1]. In [2], the authors developed a life model for lithium-ion battery generally used in electric vehicles where they studied the internal capacity fading mechanism of the battery under test.

The test can be of two types, selective life cycle test and a full life cycle test. As their name suggests, in the selective life cycle testing the battery under the test is analyzed for a few cycles and the life cycle is extrapolated using various models, while full life cycle testing estimates actual cycles a battery can withstand till it reaches failure limits.

Various prediction models can be used to extrapolate the results for life estimation, the basic parameters that dictate the life of a battery are, operational temperature, the charge/discharge rate and depth of discharge (DOD). The exact cycle life estimation of batteries may take years in the case of valve regulated lead acid (VRLA) batteries. As in [3] authors analyzed the cycle life of lithium secondary batteries along with FMEA (failure mode and effect analysis) and the safety/abuse tests to access reliability of secondary batteries. Also in [4] the authors discussed the life cycle failure rates of VRLA batteries against the expected life of the batteries and concluded that the average lifetime of VRLA batteries is in between 13 to 15 years. In [5], the authors discussed the relation of the cycle and calendar life. They used three diverse temperature ranges to achieve the end of life (EOL) for a certain battery sample. In our approach, there are four major factors that define an accelerated life cycle test of a battery:

1-Battery type, 2-Charging cycle, 3-Discharging cycle, and 4-Test conditions

A. Battery Type

Battery type is very vital, for heavy duty batteries the depth of discharge (DOD) may be selected up to 100% but for standby batteries like those used in vehicles; a low DOD must be selected. Also in batteries with memory effect like, nickel-cadmium (NiCd) batteries the DOD must be selected closer to 100% so to ensure that battery capacity is not compromised because of the memory effect.

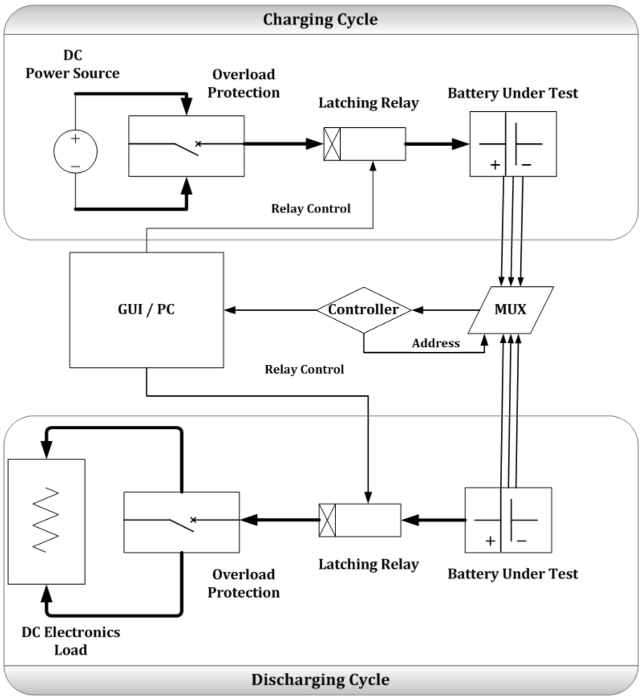

Fig. 1.Functional block diagram of the life cycle tester for batteries.

B. *Charging cycle*

The charging cycle starts where the battery is provided with external power to recharge the energy dissipated by the load. The cycle is initiated as soon as the inward current starts flowing. The charging current is selected as per specification sheet of the battery; the charge rate in ALT is kept closer to the max charge rate to simulate adverse conditions. The charging cycle completes when the charging current reaches 0.02 x current of its rated value. The test conditions are explained in later sections. Fig. 1 shows the functional block diagram of the system with major components.

C. *Discharging Cycle*

Discharge rate is very critical parameter for power sources and their accelerated life testing. This parameter dictates the capacity of any power source. The quoted capacity of any battery normally requires that its discharge current should be 0.1C. As the discharge rate increases the battery capacity decreases therefore evaluation of any battery must be done considering this fact. For a standard medium size lead-acid battery of 150Ahr capacity, the discharge rate of 25.5A leads to a rated capacity of 127.5Ahr. Thus, a discharge rate of 25.5A will guarantee 5 hours of backup time at ambient conditions. The accelerated life test is done near to the maximum discharge rate to simulate the adverse conditions. As in [6], the authors devised a method for estimating the lifetime of valve-regulated lead-acid (VRLA) batteries used in float charge service, under a variable-temperature environment. They concluded that by increasing discharge current used in a cycle lifetime test, it is possible to shorten the period required for the cycle lifetime test.

D. *Test Conditions*

1. For complete ALT, batteries should be new and unused.
2. During the entire charging cycle, electrolyte temperature must be maintained between 16°C and 43°C.
3. Electrolyte strength: batteries shall be tested with the electrolyte as supplied by the manufacturer.
4. Charging and discharging current: the charging and discharging current must be selected close to the maximum rated current. Capacity measured must be analyzed in accordance to the discharge current as mentioned in the data sheet. The high discharge current (higher than the maximum rated current) leads to a lower battery capacity. The battery discharge time can be calculated using Peukert's law as in (1)

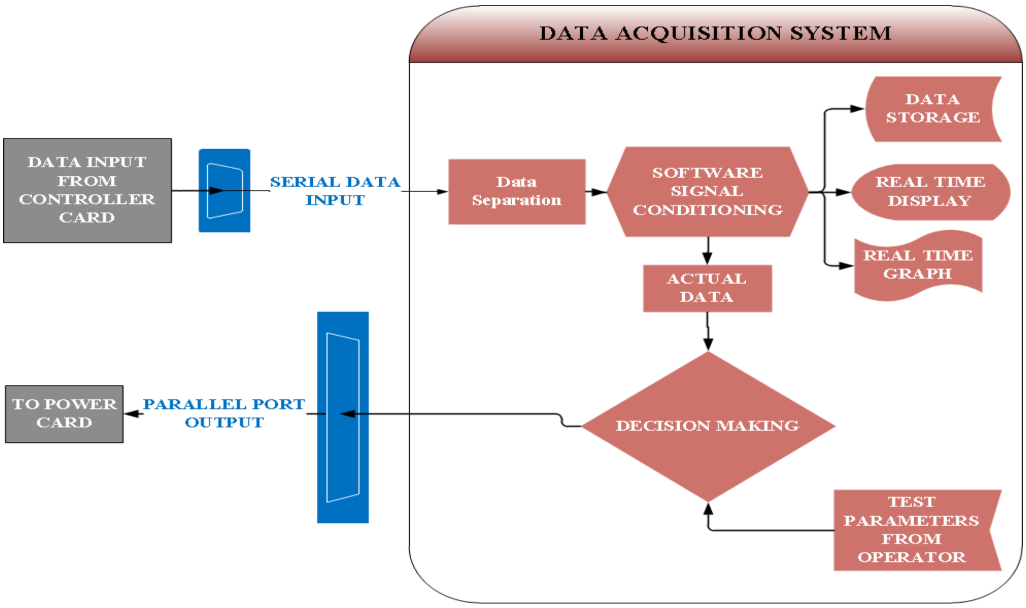

Fig. 2. Block diagram of the data acquisition system for ALT of batteries.

$$t = H\left(\frac{C}{IH}\right)^{K}$$

Where,

t is actual discharge time in hours

H is rated discharge time in hours.

I is actual discharge current in ampere.

C is the rated capacity in ampere hours.

K is the dimension-less Peukert constant, usually its value is from 1.1 to 1.3.

II. Accelerated Life Tester

The basic functional block diagram of an accelerated life tester for batteries is illustrated in Fig. 1. Major components of the tester are further explained in later subsections. A high wattage power supply provides the charging current. Over-load protection is ensured by including the electronic relay for central control. Sensors for monitoring and controlling the test are mounted on the battery under test and are connected via the main board to a PC for data acquisition. The system is designed to operate two samples simultaneously. Discharging part of the tester consists of a programmable DC load, over-load protection circuit, electronic relay control and battery under test. The DC load is programmed as per required discharge rate of the battery under the test. The test is initiated and terminated via front panel software control.

The subsystem level description is as follows:

A. Data Acquisition System Using the NI LabView

Data acquisition system (DAQ) is built on LabView interface using serial port for sensor data logging and parallel port for command and control. The functional block diagram of DAQ is presented in Fig. 2. It functions in following steps:

1. Serial data are received from the com port at the rate of 19200 bps (although it can accept any data rate in accordance with the RS232 protocol).
2. The next step is the frame identification and byte separation. This is done by adding a frame identifier at the beginning of every sequence. Acquired data is not validated until a frame identifier is detected.
3. After segregating the data, the next step is to perform signal-conditioning. Scale factors for voltage, current and temperature sensor readings are incorporated along with required off-sets in the LabView interface.
4. Real-time graphs of all the sensor reading are displayed and the data is logged into LabView database file for post processing.
5. For data recording, update rate can be set as low as 50 ms.
6. The decision making is based on the sensor data for temperature ranges, cutoff voltages and charging current. As any of the limits are reached the test is stopped.
7. A real-time clock is set as the test starts and the total test time is shown and logged for post processing.

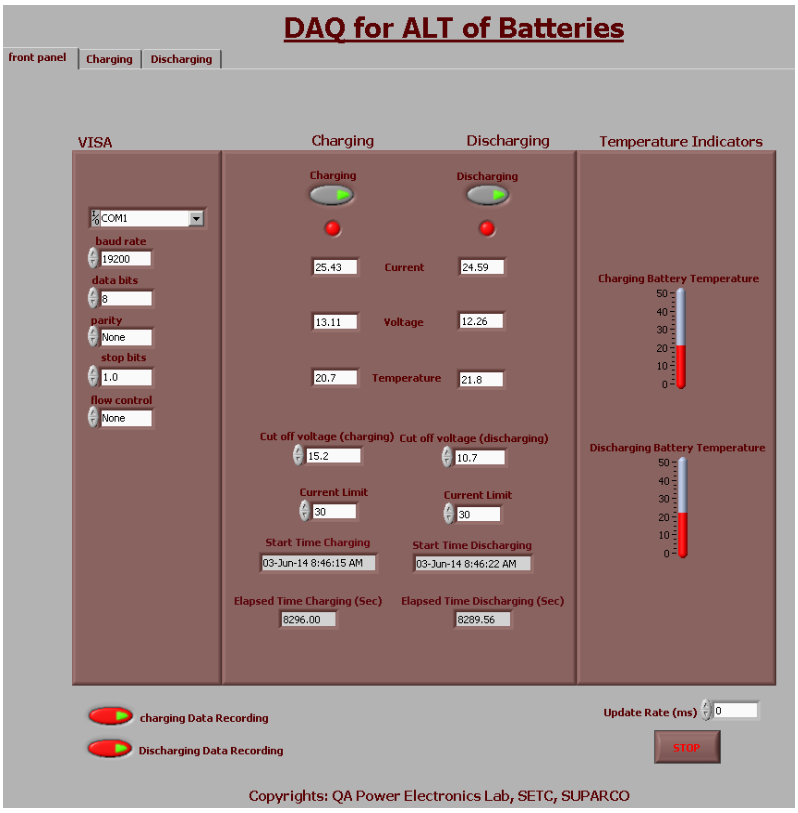

Fig. 3. Front panel of data acquisition system.

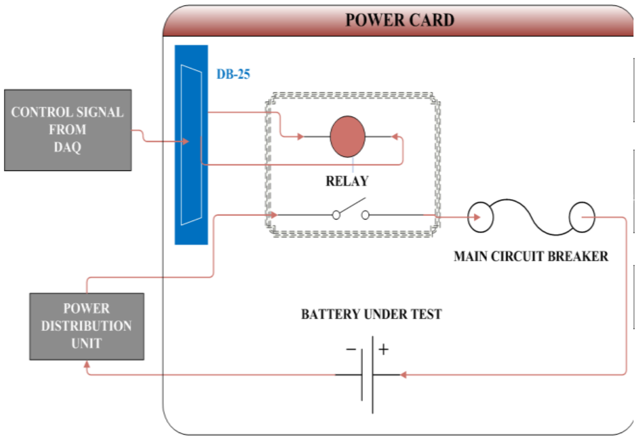

Fig. 7. Block diagram of the power board.

Fig. 8.System under operation (charge and discharge cycle, 2 simultaneous samples).

8. The test is controlled using the parallel port via electronic relays.

Fig. 3 shows the GUI of DAQ while undergoing charge and discharge cycle. The left column shows the visa settings including the baud rate, data bits, parity control, stop bit (if any) and flow control (if any). The central column shows sensor readings for the charge and discharge cycle. The central column top buttons are test initiation buttons. Real-time graphs are shown in extra tabs named as charging and discharging.

B. Power Distribution Unit

Fig. 4 shows the power distribution card where a single DC supply voltage is converted into various power busses for different cards. These conversions are DC-DC convertor based.

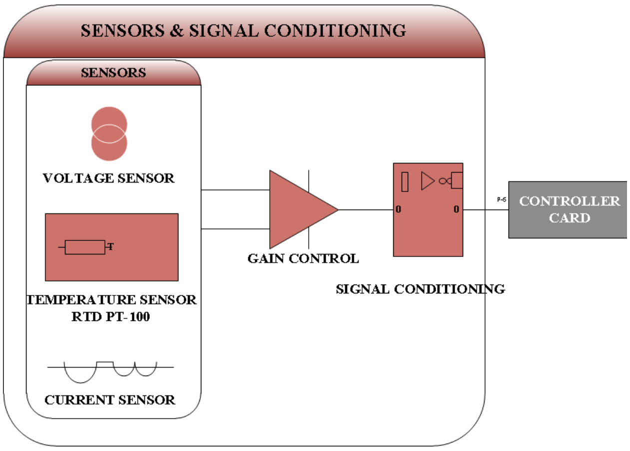

Fig. 5. Block diagram of sensors and signal conditioning unit

Filtering is done to remove any ripples that are generated due to loading. The power lines are regulated and monitored for any sudden distortion.

C. Sensor and Signal Conditioning

The sensors are directly mounted on the battery under test. PT-100 (Platinum Resistance Thermometer) is used as a temperature sensor and is mounted directly to the battery just below 25% of its height from the top. For terminal voltage monitoring, the voltage lines are directly connected to the battery. For current measurement hall sensors are used with an accuracy of 0.1A. Fig. 5 shows the sensor and signal conditioning card. All the sensors are fed directly to the main board for further processing. For temperature sensors compensated wires are used for exact measurement. Signal conditioning is done to convert signals to desired signals so that it may be fed directly to the controller. The voltage levels are controlled in between 0V-5V.

D. Main System Board

The main board consists of the functional blocks as illustrated in the Fig. 6. Multiplexer (MUX) is used to multiplex the sensor data. Controller has 8 analog ports and it can read 6 analog channels, but this is implemented to increase the capability of the system. MUX16ET is basically a 16 to 1 wire converter. This is then read by a microcontroller with its analog port and after processing the MUX data; the controller transmits the frame to serial port via level converter IC. The channel addresses are also generated by the controller and frame structure is also developed by the controller. The serial communication baud rate is set by the controller and DAQ software uses the same baud rate to receive the data.

E. Power Board

Power board is responsible for the actual charge and discharge cycle initiation and termination. The block diagram is shown as Fig. 7. The signal control is generated by the DAQ software which acts as the test initiation or termination signal. This signal is directly fed to an electronic relay which is responsible to connect the power lines for charging and discharging cycle. Circuit breaker is connected in a series for protection against any fatal accident.

F. Water Bath and Test Setup

The test is performed in a temperature controlled environment when the temperature is maintained within 20°C to 30°C. For performing the test under extreme conditions, a water bath along with heating control is required. This will decrease the battery cycles and consequently it will result in early test completion time. The battery is dipped to 75% of its volume

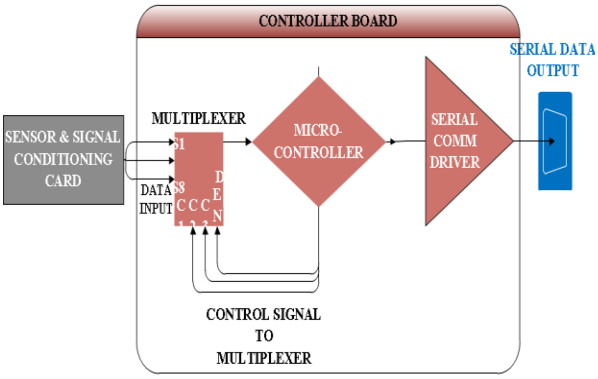

Fig. 6. Block diagram of the main system board

keeping the top layer and terminals out of the bath and the temperature sensor is mounted just below the water level.

III. EXPERIMENTAL RESULTS

The test is performed on three different samples with specifications and brand names shown in the Table 1.

TABLE I. SAMPLES TESTED FOR ALT OF BATTERIES

Sample 1	**Sample 2**	**Sample 3**
Sacred Sun	Sacred Sun	Leoch
Medium capacity VRLA	VRLA Gel	Maintenance free
SP12-150	6GFMJ-150	LP12-150
www.sacredsun.com/Upload/products/pdf/SP12-150.pdf	www.sacredsun.com/Upload/products/pdf/6GFMJ-150H.pdf	http://www.leoch.com/pdf/reserve-power/agm-vrla/lp-general/LP12-150.pdf
12V – 150Ahr	12V – 150Ahr	12V – 150Ahr
150Ahr @ 0.05C	150Ahr @ 0.1C	150Ahr @ 0.1C
Max charge rate 45A	Max charge rate30A	Max charge rate 45A
Max discharge rate1500A (5 sec)	Max discharge rate 1472A (3 sec)	Max discharge rate 1500A (5 sec)
Cutoff voltage 10.5V	Cutoff voltage 10.8V	Cutoff voltage 10.5V
Operational temperature: -10°C-45°C	Operational temperature: -20°C-45°C	Operational temperature: 0°C-40°C
200 rated life cycles for 100% DOD	700 rated life cycles for 100% DOD	200 rated life cycles for 100% DOD

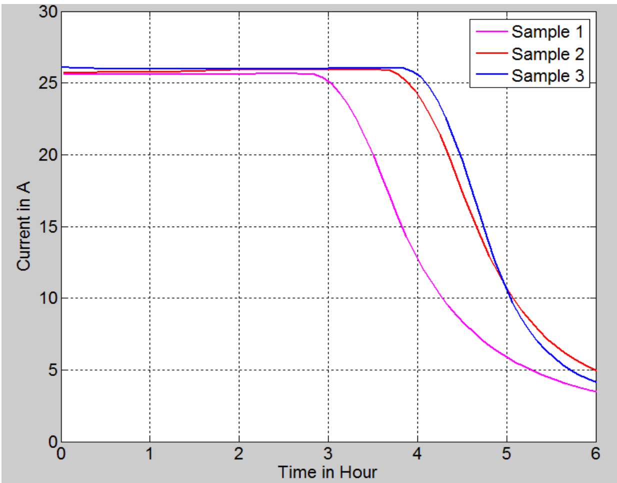

Fig. 9. Charging current profile for cycle 6 of 3 samples under test

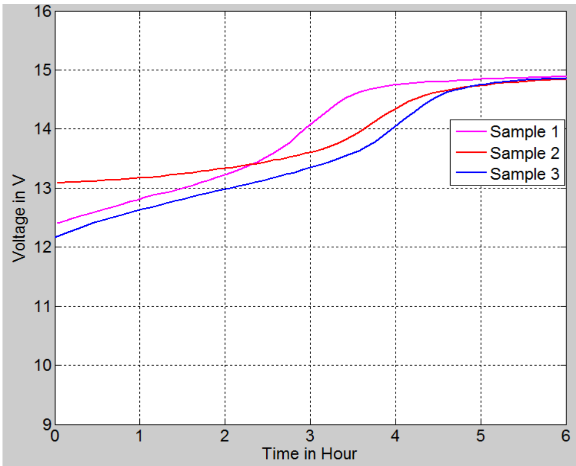

Fig. 10. Charging voltage profile for cycle 6 of 3 samples under test

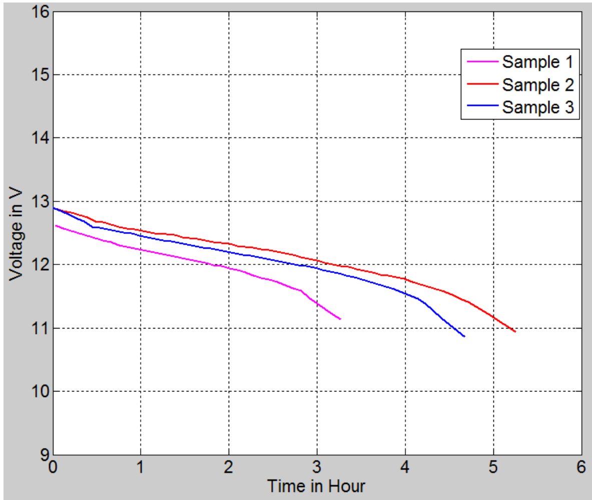

Fig. 12.Discharging voltage profile for cycle 6 of 3 samples under test

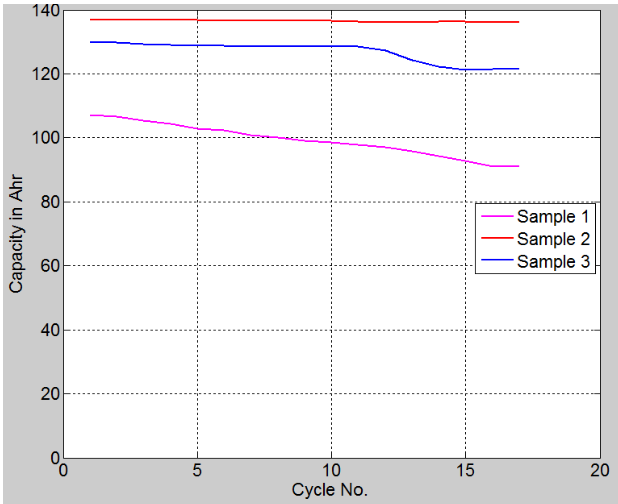

Fig. 13.Capacity curve of the samples after 16 cycles

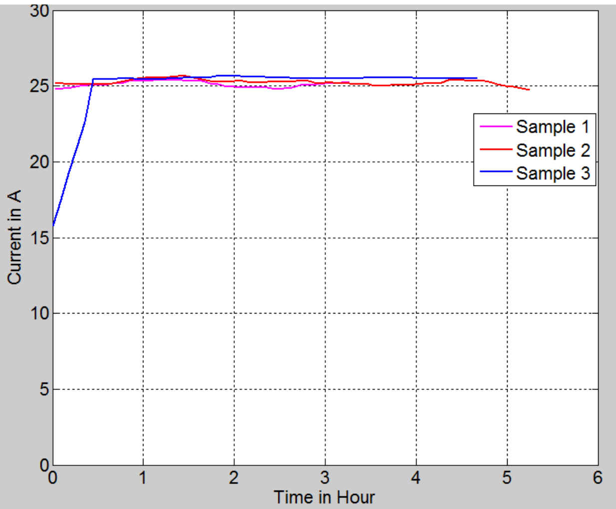

Fig. 11. Discharging current profile for cycle 6 of 3 samples under test

Full system under operation is shown in Fig. 8. In Fig. 8, the DAQ software shown on the monitor screen controls the parameters and the electronics involved are placed on the right side. As per manufacturer specifications, the discharge rate of 25.5A was selected for sample 1 and 2 and 25.8A for the sample 3. These rates lead to a rated discharge time of 5 hours; the batteries are tested until the battery capacity falls below 80% of its initial rated capacity. The charge rate is selected same as discharge. The charging voltage is selected as per battery specifications and for 12V batteries it is 14.8V±0.05V. The charging current and voltage profiles of the three samples (after testing of 16 cycles) are shown in Fig.9 and Fig. 10. For sample 1, the constant current charging lasts less than that of sample 2 and 3. For the same reason, sample 1 reaches the constant state voltage charging earlier than sample 2 and 3.

The discharge cycle profiles (for both current and voltage) are shown in Fig. 11 and Fig. 12. In Fig. 11 the current profile is shown. Constant current discharging is shown where sample 3 has a rate of 25.8A and sample 1 and 2 are discharged at a rate of 25.5A. Sample 2 has the highest discharge time illustrating it has the highest capacity.

Fig. 12 shows the terminal voltage curve while the discharging cycle is in progress. It is evident that the major portion of the battery capacity is stored in the span of 13V-11.5V. Fig. 13 shows the actual result of the capacity degradation of the three samples it is evident that the capacity of sample 1 is decreased more than the other two samples. The capacity status of the samples after 16 complete cycles is shown in Table II.

TABLE II. CAPACITY STATUS AFTER 16 COMPLETE CYCLES

Sample 1	**Sample 2**	**Sample 3**
Initial Capacity:	Initial Capacity:	Initial Capacity:
107.3 Ahr	136.8 Ahr	130.1 Ahr
Capacity After 16 Cycles:	Capacity After 16 Cycles:	Capacity After 16 Cycles:
91.1 Ahr	136.1 Ahr	121.4 Ahr
Capacity degradation:	Capacity degradation:	Capacity degradation:
15.1%	0.5%	6.7%

After 16 cycles, sample 2 has prominent result. The test is ongoing till the capacity degradation of 20% is achieved.

IV. APPLICATIONS

Applications are huge from power management of ground vehicles to commercial application in battery analysis of power sources to be incorporated in space missions. As the battery life is a critical parameter of any product so this test can be used for battery selection for any particular mission. Furthermore, applications where the dynamic use of the battery is required, where there is less time between the charge and discharge cycle; accelerated life tester may be used for selecting a suitable type of battery. In consumer applications for selecting better power sources as in [7] the authors carried out research to make the results of an accelerated life test of the cycle-life products more accurate. A more suitable model is required for predicting the cycle-life in [8] the authors developed a cycle-life estimation model for lithium-ion batteries based on limited cycle data. This model was a straight line estimation model and it had an error of 40%. Hence exponential modeling must be done in the future.

V. CONCLUSION

The paper discussed the design and development of an accelerated life tester. Partial test results were discussed and the applications are in various fields. The tester has a fast response of 50 ms per frame acquisition. The data are logged and are post processed. The setup is fully automated and requires initial test settings. The system is robust as it is tested for a continuous operation of 8 hour charging cycle and 5 hour discharging cycle for a continuous 3-month period. Data accuracy of 10mV is also achieved.

The future work includes the analysis and modeling of the life cycle using accelerated life testing results. This will include the formulation of a mathematical model that may predict the results with a certain level of confidence. As in [9] the authors discussed the accelerated life testing for battery discontinuing systems (BDS).The acceleration factor was determined to adjust the time constant of BDS for better performance. Also the accelerated life tester must be enhanced to perform life tests for all the power sources including solar cells, etc. New methods are required to accelerate this test while achieving valid results like in [10] the authors discussed the importance of new bench life-test for batteries (especially for maintenance free batteries) and provided recommendations for more precise results.

VI. ACKNOWLEDGMENTS

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