ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 12, December 2014

A Study of Capacity Fade and Life-Cycle Estimation of LiFePo4 Battery Based On Two Years Field Data

TA Abera[1], G.Bekele[2], T.Walter[3], P.Adelman[4]

Lecturer, Dept. of ECE, Adama Science &Technology University, Adma, Ethiopia[1]

Assistant Professor, Dept. ECE, Addis Ababa Institute of Technology, Addis Ababa, Ethiopia[2]

Professor Dr.Ing, Dept. of Applied Science, University, Ulm, Germany[3]

Professor, Dept. of Applied Science, University of Ulm, Germany[4]

ABSTRACT: In this paper a capacity fade and cycle-life estimation of lithium iron phosphate (LiFePO4) battery based on a two year measured field data is reported. The testing was done to complement the tests made by research institutes in a laboratory by cycling charge/discharge profiles that represent solar home systems scenario. The battery testing laboratory at further training institute (FTI) laboratory ofAdama science & Technology University, Ethiopia is used for testing.Five Pico systems consistingof LiFePO4 (LFP), 18650 type batteries with a nominal capacity of 4200mAh were distributed in a neighboring village. Capacity fade and Cycle-life estimation analysis was done on the data collected over the course of two yearswhere measurements were taken every month. Using the data collected, the capacity fade and the cycle-life of these batteries have been calculated, accordingly the result showed average capacity fade of 8% of the initial measured capacity and average cycle-life of about 6.5Years. These results exceed well above even that of what the manufacturers give as specification, which is in most cases is estimated to be 2000 cycles (5.5 years).The resulting conclusion is that the LiFePO4 battery could be the best alternative to solve one of the prominent pitfalls of solar home systems (SHS),specifically reliability and running cost. Therefore it is recommended to deploy this battery more oftenin new designs. In addition to that the result obtained from this work can be used as an input for further studies in the area of SHS.

KEYWORDS: Batteries, Ah-capacity, Cycle Life,Lithium Iron Phosphate, capacity fade**.**

I. INTRODUCTION

The ever-increasing concern in global energy demand, fuelled by the depletion of fossil fuels, has driven the search for renewable energy as a potential alternative and/or as a main stream energy source. Renewable energy is generally produced using several methods and solarphotovoltaic are among the most rapidly developing ones. Because the energy delivery through energy conversion from renewable sources is unpredictable and intermittent, combination with energy storage systems (ESSs) is required to improve the system reliability and efficiency [1]. Rechargeable electrochemical batteries have been dominating the field of renewable ESSs,where LFPbattery that uses the Commercial-grade graphite and LiFePO4 were, respectively, used as negative and positive electrode.Long-term reliability is one of the key factors for the utilization of battery ESS. In terms of cycling stability and energy density, graphite remains the first choice among the Anode (-ve) electrode materials [2]. LiFePO4 has attracted much attention as a promising cathode (+ve) electrode material because of the low cost, Fe availability, good electrochemical cycling stability, and environmentallyfriendliness [3]. At present, the combination of thegraphite negative electrode and the LiFePO4 positive electrode foruse in Li-ion batteries is one of the most promising cell chemistryfor ESS application on the basis of several factors such as cost,energy density, and cycling stability [4][5].

It is known that many battery research institutes have put together a lot of efforts to develop “Battery Cycle-Life Test Procedure” in their Laboratories and estimated accordingly thecycle-life of a battery. Probably this kind of study takes

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 12, December 2014

several years to come to a conclusion. These tests have been made mainly in the areas of electric car, plug-in hybrid cars and stationary application with high rate of discharge 3C to 5C [6].The general approach inthis method, the unique operational profiles that ESS batteries are exposed to, and the testing requirements needed to simulate the realistic load cycle profile in a laboratory environment, using a variety of load profiles including constant current discharge, pulsed discharge, and varying depths of discharge is indeed a huge task [7][8]. In addition to this it is also a common practice to make a cycle test with a bit accelerated mode using climate chambers. Most of this tests have been carried upon disassembled fully discharged cell were the electrodes thenanalyzed using: high tech instruments such as X-ray diffraction (XRD),and fieldemission scanning electron microscope (FE-SEM, JEOL JSM-7000F) with energy dispersive X-ray spectroscopy (EDS) for the observation of morphology and microstructure of the electrodes [6] [9]. In this study an attempt has been done to evaluate the life cycle & capacity fades of LFP battery using standard laboratory equipments which is very typical for developing countries using terminal characteristics.

Batteries in PV systems continually suffer from limited power for recharge and extended periods when they are left in a partially charged condition[11]. Over the last few years there has been a significant effort by the PV Global Accreditation Program (PV GAP), the IEEE Standards Coordinating Committee 21 (IEEE SCC21), and the International Electro technicalCommission (IEC) to develop standardized test procedures for batteries used in standalone PV systems. Almost all of them are laboratory based studies using sample cycle-test and make predictions based on the results[12]. PV battery test procedures in general duplicate the shallow cycling, deficit-charge cycling, low charge and discharge rates, and limited recharge or finish-charge as found in PV systems.In this study, a two year field data is collected,and the data isstatistically analyzed. Capacity fade and estimation of cycle-life have been calculated.
Study Area: Five systems have been installed in a village called “Sekekello” which is 5-8km away from Adama, in the Oromia Regional state of Ethiopia.The location of the site is (08:32N, 039:16E) and average Elevation of 1627meters. The village has got inhabitants of about 350 to 500households and it is totally un-electrified (The study also takes this opportunity to introduce the PV- solar technology to the community).

II. AIM AND APPROACH

This study aims to study the natural capacity fade of a battery as used exactly there in the field for a period of 24 months.Based on the data collected over these periods, the capacity fades and cycle life of these batteries has been estimated.
In order to achieve this aim the following approaches were followed.

i. Five systems (Pico) withLiFePO4, 18650 (cylindrical shape), nominal capacity of 42000mAh and a nominal voltage of 3.3 volt battery were distributed in the village.
ii. The initial Capacity of the batteries were measured and recorded prior to deployment

A. Details of the test:

I. Charge and discharge capacities were measured at 0.1C.
II. External environmental factors like Temperatures weren’t taken into account due to the limitation of measuring instrument and lab facilities
III. Another five replacement batteries were distributed to give service to the users when the samples were brought to lab for capacity testing at further training Institute Laboratory of Adama science and Technology University, Adama Ethiopia. (On the average this takes 2-to-3 days).
IV. Charge Professional ALC 850 Expert 2 was used for a capacity Measurement
V. Finally Excel 2010 is used to analyze the data (for Interpolation and extrapolation).

Table 1: Load connected to Systems

No	Battery	Load
1	B001	1x180lm/1.56w lamp, 2-4 cell phone

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 12, December 2014

2	B002	1x180lm/1.56w lamp,1-2 cell phones.
3	B003	1x91lm/0.78w lamp 1x180lm/1.56w lamp 2 cell phone
4	B004	1x180lm/1.56w lamp, 2 cellphone
5	B006	1x180lm/1.56w lamp

III. EVALUATION OF CYCLE-LIFE OF THE BATTERY

The most common quoted measure of cell or battery life is the cycle-life. It is usually defined as the number of cycles completed before the current capacity falls to less than 80% of the capacity when new[13]. Alternatively, for high power batteries, the useful cycle life sometimes is defined as the number of cycles completed before the internal impedance increases to double the value it was when new.

However in this work the first definition has been used. Using simple equation

$$C_{cll} = C_{init} - (20\% \; of \; C_{init}) \qquad (1)$$

where C_{cll}: *cycle life limit*

C_{init}: initial capacity

The measured initial capacity and the cycle-life capacity limit are shown in Table 2.

Table 2:Initial capacity and Cycle life limit

No	Battery	Initial capacity	Cycle life limit (80%)
1	B001	4217.70	3374.16
2	B002	4359.03	3485.62
3	B003	4238.11	3390.49
4	B004	4525.86	3620.69
5	B006	4419.54	3537.63

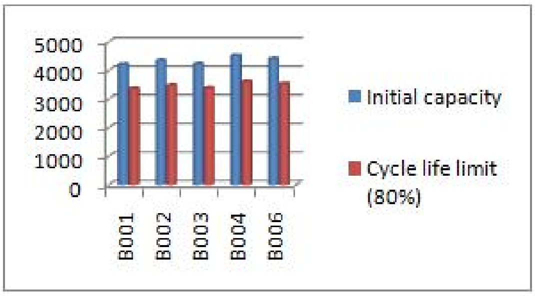

Fig. 1 initial capacity and cycle life limit calculated from measured values.

IV. RESULTS AND DISCUSSION

The result from the capacity test is shown below in fig2.

A.1 The capacity fade

Battery capacity fade in this test procedure was defined by using equation (2)

$$Capacity\ fade(\%) = \left(\frac{C_{init}-C_{final}}{C_{init}}\right) * 100 \qquad (2)$$

Accordingly results from capacity fade are shown in Table (3)

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 12, December 2014

Table 3: Capacity fades in (%) relative to Initial measured capacity

No	Initial capacity	|Final capacity	Capacity Fade (%)
B001	4217.70	3871.85	8.2
B002	4359.03	4032.1	7.5
B003	4238.11	3818.53	9.9
B004	4525.86	4168.31	7.9
B005	4419.54	4132.27	6.5

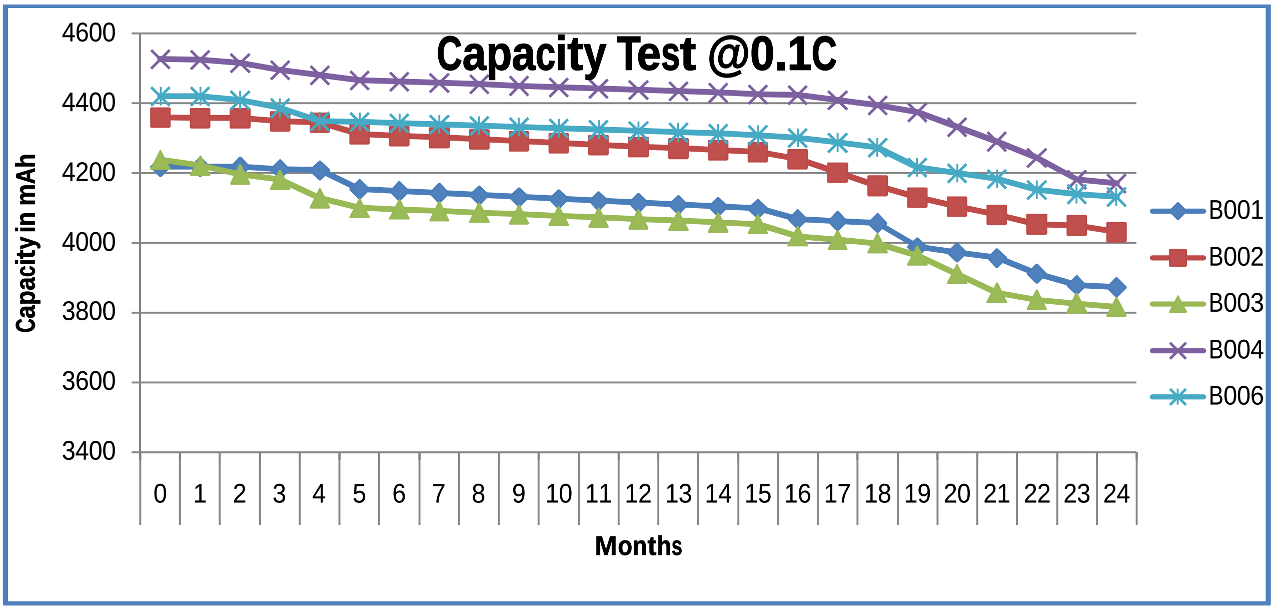

Fig2. Results from capacity test.

A.2Estimation of Cycle-life

As it is depicted from the capacity test results in fig 2, the curves are not linear as can be expected.Correspondingly in this paper the life-cycle of these batteries was estimated using the following methods.

I. A good curve fitting were achieved using trend function of excel with polynomial of degree 4 to 5, however the estimation result from this test shows exponential increase in capacity, which couldn't be explained theoretically, therefore, the curves were smoothed using moving average and center moving average methods to approximate a linear relationship. The estimation made based on this linearized trend line gave the results shown in table 4, which could be considered as roughly good estimation based on practical field data that supports the estimation made by most manufacturers in the laboratory (> 2000 cycles) [14].

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 12, December 2014

Table 4: Estimated cycle-life (Service Years)

No	For casted Months	For casted years of service
B001	70	5.8
B002	85	7.1
B003	67	5.6
B004	73	6.1
B005	96	8.0

B. Discussion

Fig1. Illustrates actual measured capacities of the Lithium iron phosphate (LFP). The data were collected over the course of two years. Percentage capacity degradation was calculated using equation (2) and shown in Table 3,the average capacity fade has been found to be 8% of the initial measure capacity.
The life-cycle estimation of this battery has been shown in Table 4. The averagecycle-life has been found to be 6 years and 5 months (6.5 yrs) which is almost double that of the lead acid (Pb) batteries.

C. Conclusion

Life cycle estimation is usually done using cycling (Charging & Discharging) under some specified condition, sometimes this is done with a slightly accelerated manner in the laboratories.
In this paper, an actual field data has been collected for two years and analyzed for capacity fade and cycle-life estimation.

The result shows that the average capacity fade of 8% of the initial measured capacity observed, and the average cycle life of about 6.5 years, that complements well the experience so far from the laboratory and the specification given by the manufacturer.
The battery is said to be reached its end of life if it fails to deliver 80% of it ratedcapacity (or degradation of more than 20% of its rated capacity).
The result here can be used as a guide line in future works elaborated and collect the field data for several years for forecasting the cycle life of LFP batteries and to study the capacity fade.
Furthermore it might be used as basisto Life Cycle Cost evaluation (LCC) of this battery, to study the economic competitivenessagainst lead acid (Pb) or nickel metal hydride (NMH). Experience shows that Lithium based batteries so far incur high initial cost than similar capacity batteries employing other chemistries.However, Lithium batteries have high energy density, long cycle life and more readily recyclable. These factors contribute to less life cycle costthat needs to be studied next.

V. ACKNOWLEDGEMENT

The author is grateful to FTI-Adama science & Technology University, DAAD, Applied Science University of Ulm (HS-Ulm) Germany and FoseraSolarsystems GmbH & Co. KGaA.

REFERENCES

1. Dunn, H. Kamath, J.-M.Tarascon, Science 334 (2011) 928.
2. Scrosati, J. Garche, J. Power Sources 195 (2010) 2419.
3. B.L. Ellis, K.T. Lee, L.F. Nazar, Chem. Mater. 22 (2010) 691.
4. K. Striebel, A. Guerfi, J. Shim, M. Armand, M. Gauthier, K. Zaghib, J. Power Sources 119e121 (2003) 951.
5. J. Shim, K.A. Striebel, J. Power Sources 119e121 (2003) 955.
6. Jae-Hun Kim, Sang Cheol Woo, Min-Sik Park, Ki Jae Kim, TaeeunYim, Jeom-Soo Kim*, Young-Jun Kim, Journal of Power Sources 229 (2013) 190e197
7. Test Results from the PV Battery Cycle-Life Test Procedure Tom Hund Photovoltaic System Applications DepartmentSandia National Laboratories Albuquerque, NM 87185-0753

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 12, December 2014

8. TA Abera, G.Bekele,T.Walter, Peter "A. Performance Evaluation of Different Batteries for Standalone Solar Photovoltaic System Application (Pico-System)",International Journal of Electrical Electronics and Telecommunication Engineering, 1384 ISSN: 2051-3240, Vol.45, Issue.1 pp1384 -1388
9. Scott B. Peterson, Jay Apt, J.F. Whitacre, Journal of Power Sources 195 (2010) 2385–2392
10. Q. Hao, Z. Jianhui, L. Jih-Sheng, Y. Wensong, IEEE Trans. Power Electr. 26 (2011) 886.
11. "AMP-HOUR COUNTING CHARGE CONTROL FORPHOTOVOLTAIC HYBRID POWER SYSTEMS" 26th IEEE Photovoltaic Specialists Conference, Anaheim, Sept. 1997
12. Evaluation of Lithium Iron Phosphate Batteries forElectric Vehicles Application 978-1-4244-2601-0/09/$25.00 ©2009 IEEE
13. J. Wang, P. Liu, J. Hicks-Garner, E. Sherman, S.
14. Soukiazian, M. Verbrugge, et al., "Cycle-life model forgraphite-LiFePO4 cells", Journal of Power Sources 196(2011) 3942-3948.
15. LiFePO4 38120(38105) Specifications

BIOGRAPHY

TA Abera
holds a Master of Science Degree inElectrical Engineering in power Electronics fromthe University ofBradford UK and a Bachelor Degree in Electrical & Electronicsfrom the Nazareth Technique college (Great Distinction).He has wide experienceaccumulated over the past several years in engineering andin renewable energy systems, having worked as alecturer, researcher and engineer in technological andindustrial institutions. At present he is a full time lecturer at Adama Science & Technology University and PhD student in a sandwich model between Adama science & Technology University and applied Science University of Ulm, Germany. His current work involves in the area of energystorage, technology.

Prof.Dr.Ing. Thomas Walter: Applied science university of Ulm

GetachewBekeleBeyene **(PhD):Has received his PhD from:** Royal Institute of Technology (KTH) in Energy Technology, **M.Sc.:** Electrical Engineering (major); Communication Engineering (minor), Addis Ababa University and Fachhochschule Kiel Germany , July 10, **B.Sc.:** Electrical Engineering, Addis Ababa University, (**Distinction**); Ass.Professor at AAiT of Adiss Ababa University.Member: ASES, WWEA, IET. Journal editor: Journal of Energy Engineering, Applied Energy. His current research interest and work related to: Electrical Power and Energy Technology: Distributed Generation, Energy conservation and Environment, Solar/ wind/ ydropower/Biogas based Standalone/grid connected energy supply systems

Prof. Peter Adelman: Applied science university of Ulm