Application Constant Temperature Charging Technique for Charging Time Reduction of Lithium Ion Battery

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Abstract- **Existing battery charging techniques such as Constant Current-Constant Voltage (CC-CV) method, Multistage Constant Current (MCC) method, Pulse Charging, Sinusoidal Ripple Approach (SRA), etc., are time consuming open loop approach which uses the fixed cell parameters and does not consider temperature variation while charging. The proposed Constant Temperature – Constant Voltage (CT-CV) charging technique suggests the closed loop scheme using instantaneous cell voltage and temperature changes with the charging current magnitude and maintaining the temperature rise at the set value as CC-CV. Charging current is controlled using PID controller added by feed forward current. This method is inexpensive as compared to the other optimization techniques which involve high quality and high cost sensors. Results shows that the proposed technique reduces the battery charging time by 24% when compared with CC-CV technique. As per the results Requirement of fast charging can be achieved through higher ambient temperature limits. The scheme can be expanded to pack level by integrating the cells.**

Index Terms- Battery charging, lithium Ion battery, PID Controller, temperature control.

I. INTRODUCTION

In today's world, laptops, smart phones and many automobiles are becoming basic needs due to their portable and rechargeable behavior and these devices can be powered by the energy storage system. Batteries can be classified into primary and secondary batteries. Primary batteries once discharged cannot be charged again. Secondary batteries can be charged again and again. Lithium-Ion batteries are more popular in the areas of portable and mobile applications due to high efficiency, high life cycle, high energy density and no memory effect. Currently many chargers are in use namely microcontroller controlled battery charger, Current pumped battery charger, grey prediction battery charger etc [1]-[4]. Lithium Ion battery also many some drawbacks such as aging increases the impedance which reduces the energy density [5]-[7], overheating and over voltage reduces the life cycle of the battery [8]-[10].State of health (SOH) [11] and state of charger (SOC) [12]-[14] are the two important parameters of the battery. Lithium Ion battery can be modeled electrically, to analyze its behavior, [13], [15] by the large capacitor which charge and discharge gives or absorbs the electrical energy. Charging techniques for Lithium Ion battery are CC-CV[16],[17], Pulse charging method [18]-[20], MCC [21]-[28] i.e. ant colony, taguchi, paricle swarm optimization etc. But all these techniques do not take rise in cell temperature into consideration. So in the proposed technique a closed loop approach is used which maintains the cell temperature at the specified limit using PID controller and also reduce the charging time of the Lithium Ion battery.

II. PROPOSED CHARGING TECHNIQUE

Temperature plays a very important role in battery charging and evaluating its performance. In the proposed closed loop technique, as shown in Fig. 1, the cell voltage and temperature are utilized to maintain the charging current magnitude keeping the temperature rise within the limits. PID controller provides path to the charging current while maintaining the battery temperature within the specified limit. Feed forward current, which is exponentially decreasing from 2C to 1C (C is the charge capacity), is added to PID signal to reduce its gain. The higher charging current, as shown in Fig. 2, is given at the start of the CT (Constant Temperature) phase maintaining the temperature within the limit, and the current decreases exponentially till the end of

CT phase. Once the nominal voltage is achieved, the battery will charge using CV mode where the current is decreases to 0.1C.

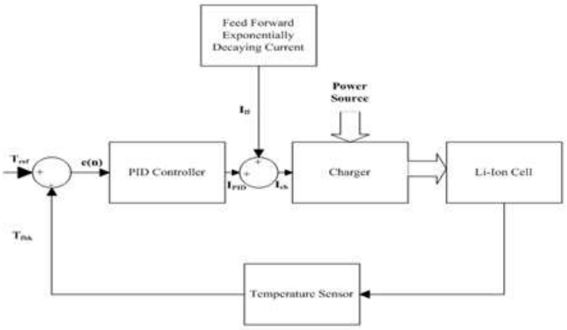


Fig. 1. Block diagram of CT-CV charging scheme

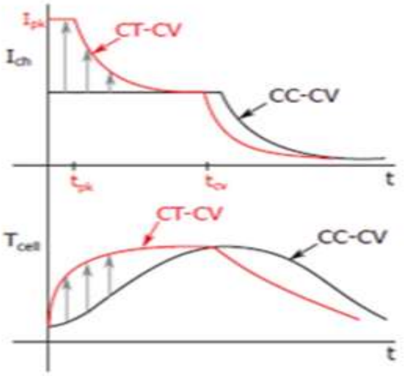


Fig. 2. CT-CV charging in comparison with CC-CV charging

The PID equation used in the model are represented by Eq. 3.16 to Eq. 3.20.

$$e(n) = T_{ref}(n) - T_{fbk}(n) \tag{1}$$

$$I_p(n) = K_p e(n) \tag{2}$$

$$I_i(n) = I_i(n-1) + K_i e(n) \tag{3}$$

$$I_d(n) = K_d[e(n) - e(n-1)] \tag{4}$$

$$I_{PID}(n) = I_p(n) + I_i(n) + I_d(n) \tag{5}$$

Where e(n) is the controller error, T_{ref} is the reference temperature, T_{fbk} is the cell temperature, I_{PID} is the PID current, I_{ff} is the feed forward current, I_{ch} is the cell charging current, K_p is the proportional gain, K_i is the integral gain, K_d is the derivative gain, I_p is the proportional current, I_i is the integral current and I_d is the derivative current.

The feed forward open loop system is added to the output of the PID controller to improve the system performance without affecting stability. In the battery charging, feed forward system is the exponentially decreasing current signal from 2C to 1C during constant temperature mode. If feed forward current is not added to PID than the controller gain value should be high which is not convenient when there is lot of discrepancies in system parameters. The feed forward current is represented by Eq. (6).

$$I_{ff} = \left\{ \begin{array}{ll} 2C: & 0 \le t < t_{pk} \\ C\left(1 + e^{-(t-t_{pk})/\tau}\right): & t_{pk} \le t < t_{cv} \end{array} \right\}$$

(6)

Where t_{pk} is the time when the current is at its peak value, t_{cv} is the time at which CV mode is reached, τ is time constant of exponential delay. The technique can be improved further by evaluating feed forward term using the electrical and thermal model of the battery.

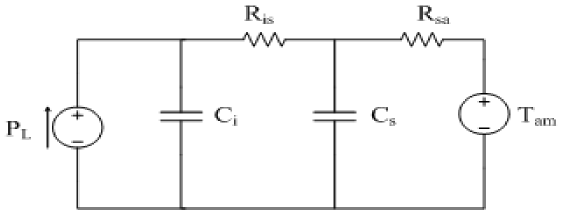


Fig. 3. Lithium Ion battery thermal model

The power loss causes the rise in surface temperature (T_s) as well as the internal temperature (T_i) of the cell. The thermal model [29] as shown in Fig. 3 is represented by Eq. 7 & 8.

$$C_i \frac{dT_i}{dt} = P_L - \frac{T_i - T}{R_{is}}$$

(7) ... *(3.14)*

$$C_s \frac{dT_s}{dt} = \frac{T_i - T}{R_{is}} - \frac{T - T_{am}}{R_{sa}} \tag{8}$$

… (3.15)

Where C_i is the cell internal heat capacity, C_s is the cell surface heat capacity, T is the cell temperature, T_{am} is the cell ambient temperature, R_{is} is the thermal resistance of cell between internal to surface, R_{sa} is cell surface to ambient thermal resistance. The flow chart of the proposed technique is shown in Fig. 4.

III. RESULT

This section shows the comparative experimental results of the proposed technique and the conventional CC-CV technique. The test is performed on the 4.2V Lithium Ion battery whose rated capacity is 2.3A and nominal voltage is 3.6V. TABLE II shows reduction in the charging time when proposed CT-CV technique is used. Fig 5 shows and TABLE II shows that the battery is charged 24.33% faster by giving the exponentially

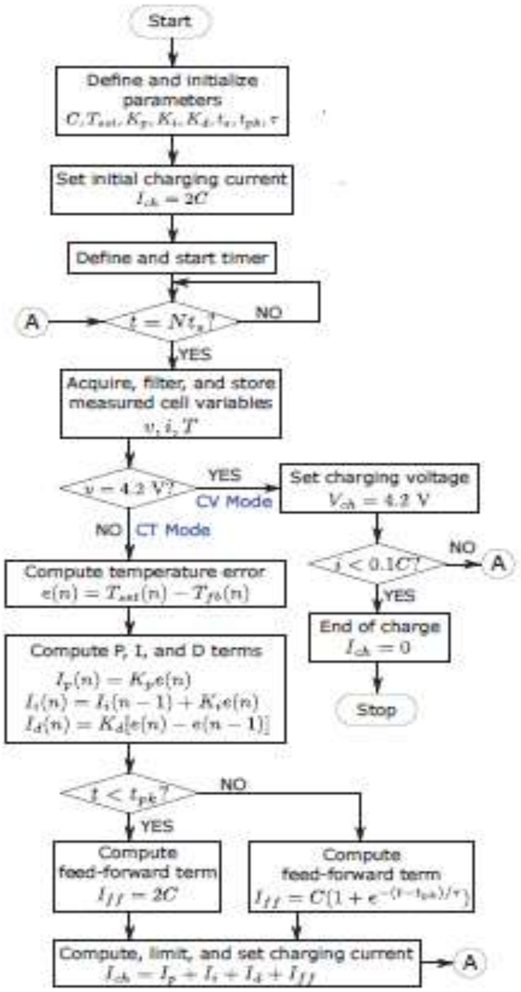
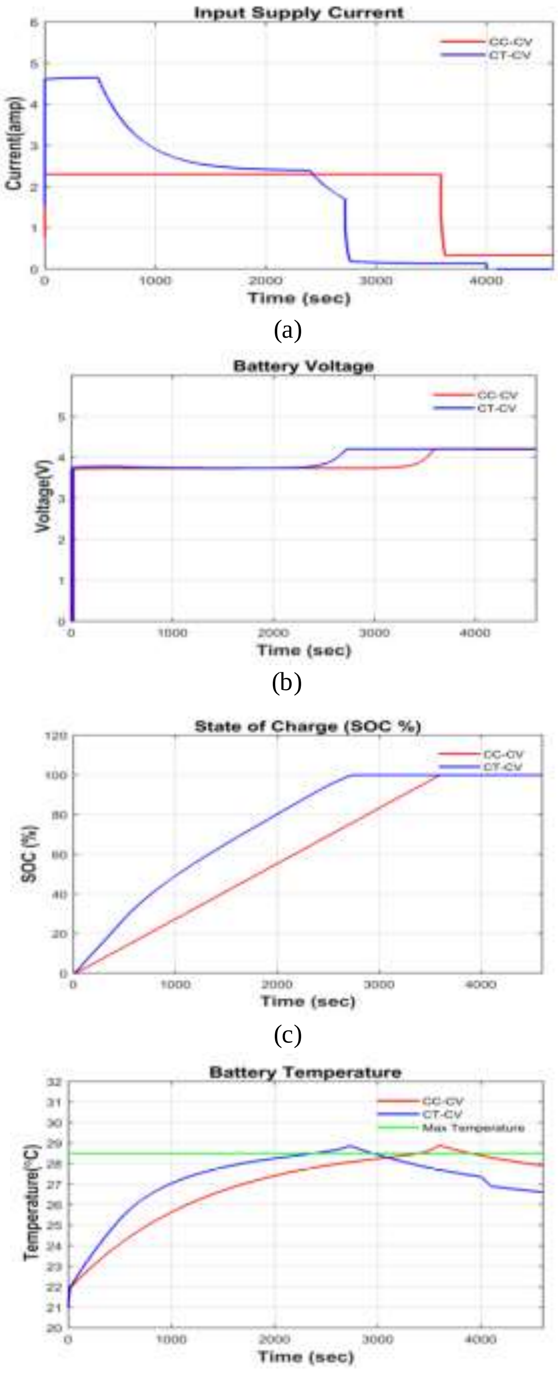


Fig.4. Flowchart of proposed CT-CV method

decreasing signal, maintaining the reference temperature at 28.5°C and the room temperature is 21°C.

TABLE II REDUCTION IN CHARGING TIME

S.no.	SOC (%)	Time Taken in CC-CV (mins)	Time Taken in CT-CV (mins)	% Reduction in Charge time
1	10	6.38	3.17	50.29
2	20	12.34	6.15	50.15
3	30	18.31	9.13	50.10
4	40	24.27	12.71	47.62
5	50	30.24	17.11	43.40
6	60	36.20	22.11	38.93
7	70	42.17	27.48	34.84
8	80	48.13	33.07	31.29
9	90	54.10	38.74	28.39
10	100	60.44	45.73	24.33


Input Supply Current

(a)

Battery Voltage

(b)

State of Charge (SOC %)

(c)

Battery Temperature

(d)

Fig. 5. Experimental results comparing proposed CT-CV and CC-CV charging

IV. CONCLUSION

This section concludes the presented study in the field of battery charging system. This work has proposed an improved charging technique namely CT-CV to improve the performance and reduce the charging time of the battery. The proposed method reduces the charging time by 24.33% maintaining the rise in battery temperature same as CC-CV charging which improves battery life. The Li-Ion battery charging time for 4.2V battery using CC-CV method is 60.44 minutes and charging time using CT-CV method is 45.73 minutes. For faster charging requirements the cell temperature limit can be raised in expense of cycle life. This method can be expanded to pack level by integrating the cells.

REFERENCES

[1] J. H. Lee, H. S. Bae & B. H. Cho, "Resistive Control for a Photovoltaic Battery Charging System Using a Microcontroller" *IEEE Transactions on Industrial Electronics*, vol. 55, no. 7, pp. 2767-2775, July 2008

[2] L.Rui Chen, J.J. Chen, Neng-Yi Chu & Gia-Yo Han. "Current-Pumped Battery Charger" *IEEE Transactions on Industrial Electronics*, vol. 55, no. 6, pp. 2482-2488, June 2008

[3] Liang-Rui Chen, Chuan-Sheng Liu & Jin-Jia Chen. "Improving Phase-Locked Battery Charger Speed by Using Resistance-Compensated Technique" *IEEE Transactions on Industrial Electronics,* vol. 56, no. 4, pp. 1205-1211, April 2009

[4] Liang-Rui Chen, Roy Chaoming Hsu & Chuan-Sheng Liu. "A Design of a Grey-Predicted Li-Ion Battery Charge System" *IEEE Transactions on Industrial Electronics*, vol. 55, no. 10, pp. 3692-3701, October 2008

[5] Zheng Chen, Bing Xia, Chunting Chris Mi, & Rui Xiong. "Loss-Minimization-Based Charging Strategy for Lithium-Ion Battery" *IEEE Transactions on Industry Applications*, vol. 51, no. 5, pp. 4121-4129, September/October 2015

[6] L. R. Chen, S. L. Wu, D. T. Shieh, and T. R. Chen, "Sinusoidal-ripple-current charging strategy and optimal charging frequency studyfor Li-ion batteries," *IEEE Trans. Ind. Electron.*, vol. 60, no. 1, pp. 88–97, Jan. 2013

[7] Ala A. Hussein, Abbas A. Fardoun & Samantha S. Stephen." An Ultra-fast Maximum Power Point Tracking Technique for Optimal Battery Charging". *IEEE Transactions on Sustainable Energy*, vol. 51, no. 1, pp. 111–120, November 2016

[8] Souleman Njoya Motapon, Alexandre Lupien-Bedard, Louis-A. Dessaint, Handy Fortin-Blanchette & Kamal Al-Haddad. "A Generic Electro-Thermal Li-ion Battery Model for Rapid Evaluation of Cell Temperature Temporal Evolution*" IEEE Transactions on Industrial Electronics*, vol. 55, no. 2, pp. 151–160, September 2016

[9] A. El Mejdoubi, A. Oukaour, H. Chaoui, H. Gualous, J. Sabor, and Y. Slamani, "State-of-charge and state-of-health lithium-ion batteries diagnosis according to surface temperature variation," *IEEE Trans. Ind. Electron*., vol. 63, no. 4, pp. 2391–2402, 2016

[10] Bo-Ruei Peng, Shun-Chung Wang, Yi-Hua Liu, Yan-Syun & Huang. "A Li-ion Battery Charger Based on Remaining Capacity with Fuzzy Temperature Control" *IEEE,* vol. 64, no. 5, pp. 112–122, June 2016

[11] H. T. Lin, T. J. Liang, and S. M. Chen, "Estimation of battery state of health using probabilistic neural network," *IEEE Trans. Ind. Inf.*, vol. 9, no. 2, pp. 679-685, May 2013

[12] Zhihang Chen, Shiqi Qiu, M.Abul Masrur & Yi Lu Murphey. "Battery State of Charge Estimation Based on a Combined Model of Extended Kalman Filter and Neural Networks" *Internation Joint Conference on Neural Network*,vol. 50, no. 4, pp. 2156-2163, October 2011

[13] H. Rahimi-Eichi, F. Baronti, and M. Y. Chow, "Online adaptive parameter identification and state-of-charge coestimation for lithium-polymer battery cells," *IEEE Trans. Ind. Electron*., vol. 61, no. 4, pp. 2053–2061, Apr. 2014

[14] Mehdi Gholizadeh & Farzad R. Salmasi. "Estimation of State of Charge, Unknown Nonlinearities and State of Health of a Lithium-Ion Battery Based on a Comprehensive Unobservable Model" *IEEE Transactions on Industrial Electronics*, vol. 61, no. 3, pp. 1335-1344, March 2014

[15] Olivier Tremblay, Louis-A. Dessaint & Abdel-Illah Dekkiche. "A Generic Battery Model for the Dynamic Simulation of Hybrid Electric Vehicles" *IEEE Vehicle Power and Propulsion Conference*, vol. 45, no. 6, pp. 284 – 289, June 2007

[16] C. H. Lin, C. Y. Hsieh, and K. H. Chen, “A Li-ion battery charger with smooth control circuit and built-in resistance compensator for achieving stable and fast charging,” *IEEE Trans. Circuits Syst.* I, vol.57, no. 2, pp. 705–712, Feb. 2010

[17] Bo-Yuan Chen & Yen-Shin Lai.” New Digital-Controlled Technique for Battery Charger With Constant Current and Voltage Control Without Current Feedback” *IEEE Transactions on Industrial Electronics*, vol. 59, no. 3, pp. 1545-1553, March 2012

[18] L. R. Chen, “Design of duty-varied voltage pulse charger for improving Li-ion battery charging response,” *IEEE Trans. Industrial Electronics*, vol. 56, no. 2, pp. 480–487, Feb 2009

[19] L. R. Chen, “A design of an optimal pulse charge system by frequency varied technique,” *IEEE Trans. Industrial Electronics*, vol. 54, no. 1, pp. 398–405, February 2007

[20] Judy M. Amanor-Boadu, Mohamed A. Abouzied & Edgar Sánchez-Sinencio. “An Efficient and Fast Li-ion Battery Charging System Using Energy Harvesting or Conventional Sources” *IEEE Trans. Industrial Electronics*, vol. 65, no. 9, pp. 7383–7394, December 2017

[21] Y. H. Liu, J. H. Teng, and Y. C. Lin, “Search for an optimal rapid charging pattern for lithium-ion batteries using ant colony system algorithm,” *IEEE Trans. Ind. Electron*., vol. 52, no. 5, pp. 1328–1336, Oct. 2005

[22] S.-C. Wang and Y.-H. Liu, “A PSO-based fuzzy-controlled searching for the optimal charge pattern of Li-ion batteries,” *IEEE Trans. Ind. Electron*., vol. 62, no. 5, pp. 2983–2993, 2015

[23] J. Jiang, C. Zhang, J. Wen, W. Zhang, and S. M. Sharkh, “An optimal charging method for Li-ion batteries using a fuzzy-control approach based on polarization properties,” *IEEE Trans. Veh. Technol*., vol. 62, no. 7, pp. 3000–3009, Sept. 2013

[24] Yan Ma, Peng Duan, Yanshuai Sun & Hong Chen. “Equalization of Lithium-ion Battery Pack based on Fuzzy Logic Control in Electric Vehicle” *IEEE Trans. Ind. Electron*., vol. 65, no. 8, pp. 6762-6771, January 2018

[25] Y. H. Liu and Y. F. Luo, “Search for an optimal rapid-charging pattern for Li-ion batteries using the Taguchi approach,” *IEEE Trans. Ind. Electron*., vol. 57, no. 12, pp. 3963-3971, Dec. 2010

[26] Judy M. Amanor-Boadu, Anthony Guiseppi-Elie & Edgar Sánchez-Sinencio. “Search for Optimal Pulse Charging Parameters for Li-ion Polymer Batteries Using Taguchi orthogonal Arrays” *IEEE Transactions on Industrial Electronics*, vol. 65, no. 11, pp. 8982-3992, February 2018.

[27] Feng Wang, Naxin Cui & Haoran Fang. “Multi segment Charging Strategy for Lithium ion Battery Based on Taguchi Method” *IEEE*, vol. 64, no. 11, pp. 982-992,2017.

[28] Y. H. Liu, C. H. Hsieh, and Y. F. Luo, “Search for an optimal five-step charging pattern for Li-ion batteries using consecutive orthogonal arrays,” *IEEE Trans. Energy Convers*., vol. 26, no. 2, pp. 654–661, Jun. 2011.

[29] Cong Zhu, Xinghu Li, Lingjun Song & Liming Xiang. “Development of a theoretically based thermal model for lithium ion battery pack” *Journal of Power Sources*, vol. 24, no. 1, pp. 155-164, September 2012.