Constant-Temperature Constant-Voltage Method for Li-ion Batteries to Reduce the Charging time

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Abstract—**Lithium-ion batteries have high energy density, high specific energy, good cycle life, low self-discharge, and are environment friendly. Because of these qualities, they have emerged as a popular rechargeable battery chemistry with a wide variety of applications in portable electronics, electric vehicles (EVs), grid energy storage, and renewable energy. Open –loop approach is the largely used technique for charging Li-ion batteries, where the prior knowledge of cell parameters can be used to predefine the charge profile. Closed loop charging technique is in need, the charging current magnitude can be modulated using instantaneous cell voltage and temperature. Compared to constant-current constant-voltage (CC-CV) technique the closed loop technique achieves 20% fast charging. Under the given total charge time it causes 20% lower temperature. Closed loop technique can charge large capacity battery with less time. In smart phone charging this technique maintains temperature while fast charging.**

Key Words—Battery chargers, closed-loop charging, constant temperature charging, CT-CV charging, fast charging, lithium-ion batteries, temperature control.

I. INTRODUCTION

A battery is connection of group of electrochemical cells which store electric charge and generate straight current by changing chemical energy into electrical energy. A Lithium-ion battery come under rechargeable battery which is used for easy to carry electronics and electric vehicles and also it is becoming popular in the fields like military and aerospace. Now a days most of the Lithium-ion batteries are manufactured by graphite-based anode. Where the Lithium-ion can be able to receive and reject in a small potential range of 0.05 to 0.3V. Lithium-ion batteries have two continuous steps which are use for charging. The steps are battery charges at constant-current till voltage extends to pre-determined limit which is 4.1 or 4.2V, through constant electric voltage charging till electrical conduction lowers towards set value. This process is said to be constant electric current-constant electric voltage (CC-CV) conduction.

In CC-CV charging under CV mode decaying current profile can be seen. This can be detected by sequence declining steps of current. The explained technique, is called a multistage constant electric current (MCC) charging, it avoids necessity for produced voltage regulation measurements in conduction power-electronics. Various optimization techniques can be used for optimization of current dimensions and interval for every particular step in MCC-charging for every cell.

The charge of most lithium ion batteries should not exceed 45^0C, and the discharge should not exceed 60^0C. This is not a particular limit science it can pushed higher but the life span of the battery cannot be guaranteed. Lithium ions perform well at high temperatures, but long-term exposure to heat will reduce life. The Lithium-ion battery have the good ability to charge in cold weather compared to other batteries but temperatures like too high or too low are still compromise their ability to charge and discharge energy. In cold weather it increases the internal resistance and lowers the capacity.

This paper mainly tells higher charging in limited time by using the battery temperature as a key point. This type of charging can be implemented in electric charging stations, industrial power backups etc, where we cannot waste time for charging the battery of electric vehicles instead we need fast charging technique without affecting the battery life.

II BLOCK DIAGRAM

Block diagram shows the charger is connected to the power source. The charger takes the power and gives to the Lithium-ion cell so the cell starts to charge. But after some time the cell starts to increase its temperature which may affect cell property and may decrease battery life. So temperature sensor is given as the feed back to PID controller. In PID controller the rated temperature is set as 28.5^0C (room temperature). When temperature readings come to PID controller through temperature sensor, PID controller decides whether it should conduct in CC method or CV method based on temperature readings. This helps to balance temperature in cell and also helps in 20% quicker charging compared to other methods.

Control circuit diagram of the suggested constant temperature constant voltage conducting technology is shown in Figure 1. The main purpose of this technology is to ensure closed-loop charging, change the magnitude of charging current associated with battery and accelerate charging speed when the specified temperature rises. Temperature plays a very important role here.

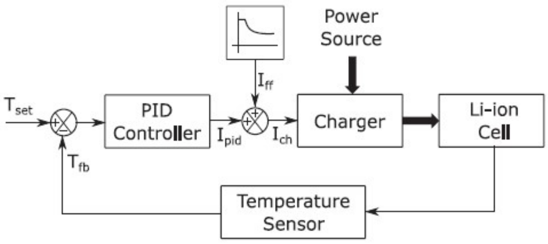

Fig1:Block diagram for proffered CT-CV charging technique

III IMPLIMENTATION

We have used MATLAB Simulink for simulation and results are discussed and analysed as below. In electrochemical and mechanical degradation mechanism with Lithium containing cell factor temperature plays an important role. This deterioration in cell conduction, safety, and health is the result of degradation. For example the faster charging can be enabled by maintaining a constant temperature rise as conventionally used in CC-CV method. As a result charging this is reduced without affecting the life cycle of cell. Hence the Lithium-ion cell can charged at a greater current (1C) by kipping temperature rise at a given allowable limits. In order to achieve the best results, magnitude of current is controlled accordingly with the cell temperature. The law of control is a standard PID controller led by a feed forward expression which represented below. Discrete domain equation of PID controller is given

$$e(n) = T_{set}(n) - T_{fb}(n)$$
$$I_p(n) = K_p e(n)$$
$$I_i(n) = I_i(n-1) + K_i e(n)$$
$$I_d(n) = K_d[e(n) - e(n-1)]$$
$$I_{pid}(n) = I_p(n) + I_i(n) + I_d(n)$$

Where e(n) is controller error. T_{set} and T_{fb} indicates set point and feedback values of cell temperature and K_p, K_i and K_d are controller gains for proportional, integral and derivative terms.

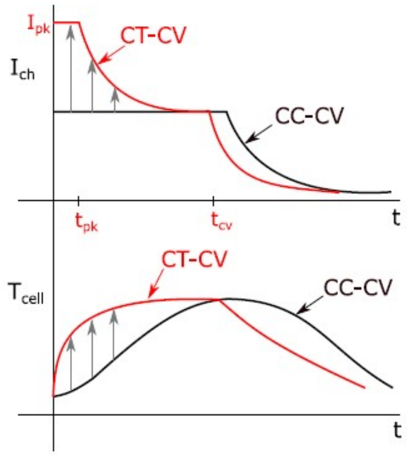

Fig2: Conceptual structure of CT-CV charging is compared with CC-CV charging, with same temperature rise.

Fig2 represents temperature profit is varied, as it reaches a low value during CC phase, whereas a greater value at end and beginning of CV mode. This indicates the scope of increasing current at charging in initial part of CC phase, whereas reduction during CV mode is approaching. By the above method it can achieve similar temperature as CC-CV conducting but it is achieved very soon than that of CC-CV technique. Charging current should be reduced about 70% state-of-charge (SOC), to keep away from plating Lithium metal on anode. An exponentially decaying current profit is used to meet the above requirements. The decaying current is varied from baseline value 2C to the ultimate value 1C, current expression I_{ff} as represented down.

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

where C indicates C-rate of the battery, t_{pk} is time for which baseline conducting current is kept at its peak value (2C)

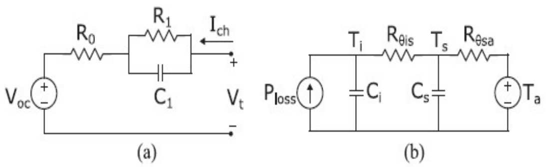

Fig3: Modelling of Lithium-ion cell.

Ti = internal temperature,

Ts = Surface temperature, and

Ta = Ambient temperature.

Fig3 represents typical one-time-constant (OTC) equivalent design known as Thevenin model of Lithium containing cell where R_0 and R_1 indicates ohmic resistance and polarization resistance and R_{int} represent inner opposition, regarding voltage V_{oc} denote open circuit voltage, V_t denotes terminal voltage. Polarization capacitance C_1 is used for transitory response while charging and discharging. Considering 0 alternating electric current component, charging current (I_{ch}) moves across series resistor R_0 and R_1 leads to finite power loss.

$$P_{\text{loss}} = I_{\text{ch}}^2 (R_0 + R_1).$$

SOC with arch shaped curve have greater quantity at extremely less and extremely large SOC. Resulting non-linear cell models which do not effortlessly code to transfer function examination. So, therefore acceptable controller gain could be estimated under Zeigler-Nicholls tuning. Dissipated power (P_{loss}) leads to raise in temperature internally (T_1) and above the cell surface (T_s) which is represented in second-order thermal model. Differential equation is given by,

$$C_i \frac{dT_i}{dt} = P_{\text{loss}} - \frac{T_i - T_s}{R_{\theta\text{ is}}}$$

$$C_s \frac{dT_s}{dt} = \frac{T_i - T_s}{R_{\theta\text{is}}} - \frac{T_s - T_a}{R_{\theta\text{sa}}}$$

where C_i = Internal capacity

C_s = Surface heat capacity

T_i = Internal temperature

T_a = Ambient temperature

$R_{\Theta is}$ = Internal to surface thermal resistance

$R_{\Theta sa}$ = Surface to ambient thermal resistance

The electrical and thermal models is applied with PID temperature control loop, while considering the charge as controlled current origin, reasonable charging current profiles are obtained by numerical simulation.

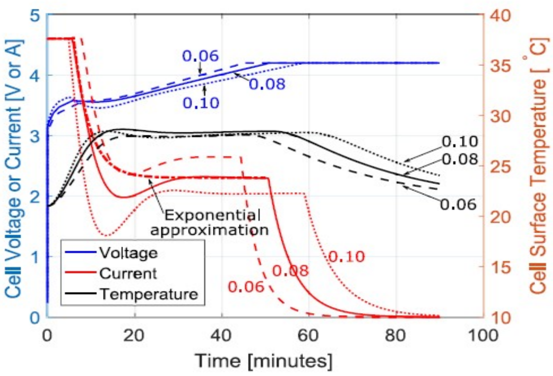

Fig4: Li-ion charging profiles got by simulation in PLECS software for various values.

Fig4 indicates the charge profile obtained by simulation of above indicated figure using PLECS for various values of R_{int}. R_{int} value varies to aging and cell to cell differences. So these parameters are considered and are monitored, which results in estimation of current profiles which serves as charging current term (I_{ff}). The control method used for current profiling is the major differences between the conventional and proposed CT-CV charger, there is no alternation in power converter circuit while accommodating CT-CV charging. If the CT-CV charging system contains micro-controller then software code is required to shift the CT-CV charging. The temperature sensors are used in existing battery Management System (BMS) to address the safety aspects. These same sensors are used in proffered CT-CV charging technique, hence avoiding extra cost.

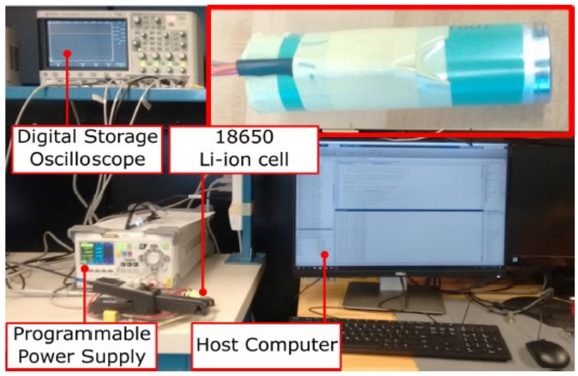

Fig5: Photography of experimental structure

Parameter	Value
Model	Samsung INR18650-25R
Format	Cylindrical cell
Chemical System	$LiNiCoAlO_2$ (NCA)
Nominal Voltage	3.6 V
Nominal Capacity	2,300 mAh
Charging Condition	CC-CV: @1C (2.3 A), 4.2 V max, 0.1C (0.23 A) cut-off
Discharging Condition	CC @1C (2.3 A), 2.8 V cut-off
Nominal R_0	70 mΩ
Nominal R_1	10 mΩ
Approx. weight	44 g

Battery Specification

Fig5 shows the experimental structure used to examinate in this proffered CT-CV charging method. Samsung INR18650-25R rod shaped cells are most popular cells used in various applications. The above referred cell is used by both CC-CV and CT-CV conducting. The temperature sensor used here is LM335A which is a solid state heat sensor that are utilized in sensing the heat of the cell.

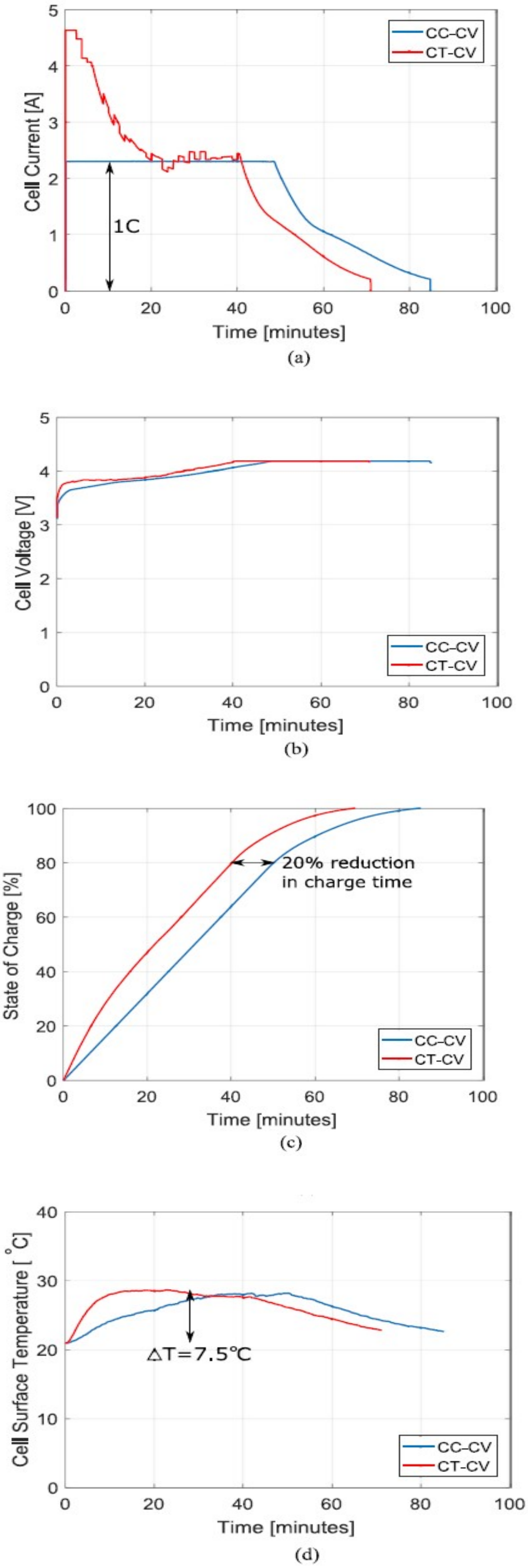

Fig6: Comparison between CT-CV charging and CC-CV charging with same temperature rise.

Fig6 represents the charging current, cell temperature, cell voltage and SOC obtained by using two charging technique, where current at CC-mode is at 1C (2-3A) charging while rise in SOC where coulomb counting is used for SOC computation i.e. integrating charging current. In CT-CV method the cell takes 70 minutes to get fully charged, on the other hand CC-CV technique takes 85 minutes. The proposed technique charges the cell 18% faster by keeping constant temperature rise of 7.5^{0}C from 21^{0}C to 28.5^{0}C. 20% charging time is reduced in this case and it is shown in figure 6(d). To increase the cycle life of cell, the cell charges to 80% of SOC or there will be no time to charge the cell completely. In this type of case CC-CV mode will take 50 minutes where as CT-CV would take about 40minutes. Hence in this method the charging time is decreased to 20%. By taking time to charge upto 50% SOC, there will be 30% decrease in charging time.

IV RESULTS AND DISCUSSION

The simulation model of constant-temperature constant-current constant-voltage (CT-CC-CV) method. Simulation circuit that is almost similar to constant current constant voltage, extra circuit it consists is thermal sensor. In this model the PID controller is connected with the temperature sensor, current and voltage constants. When the heat condition is within 28.5^{0}C the battery will be charging in constant current charging. Because of the current charging the battery starts to heat up so the thermal sensor gives the information to PID controller when the temperature reaches 28.5^{0}C to 30^{0}C and switches to constant voltage charging so that the temperature starts to reduce gradually.

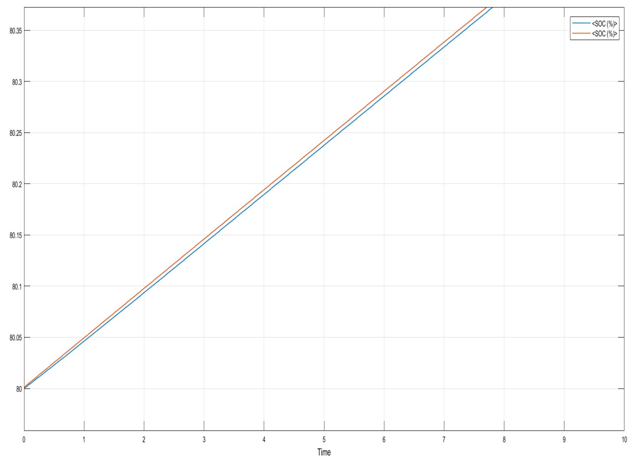

Fig7: Simulation result of CT-CC-CV charging SOC versus time.

In fig7 the graph is SOC versus time. The red line in the graph represents CT-CV charging and the blue line indicates the CC-CV charging. In most of application, battery gets charged up to 80% SOC because to increase cycle life and some time there is no enough time to charge fully. If this happens the proposed CT-CV method could charge battery in 40 minutes where as the CC-CV method would take 50 minutes. Hence CT-CV charging reduces the charging time approximately 20% compare to CC-CV charging. Hence CT-CV has much faster effect in charging.

V Conclusion

Battery temperature is considered to be a key degradation indicator to verify the CT-CV charging technology of lithium-ion batteries through experiments. The constant temperature rise in CC-CV technology enables the proposed method to achieve a faster charging speed of 20%. Within a specified conducting time, it will reduce rise in temperature by 20%. By mixing the proposed technology with SCR and pulse current charging, there will be reduction in the rise of temperature. In closed-loop protocol, the conducting current is modulated with respect to cell temperature and thermal environment. The need to increase the charging speed can be achieved by increasing the rated temperature. The arrival of advanced lithium containing cells, technology have range to increase the baseline conducting current below 2C to promote rapid conducting. Lastly, research shows the profit/gain of the proposed charging method.

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References

[1] S. S. Zhang, “The effect of the charging protocol on the cycle life of a Li-ion battery,” J. Power Sources, 2006.

[2] P. A. Cassani and S. S. Williamson, “Significance of battery cell equalization and monitoring for practical commercialization of plug-in hybrid electric vehicles,” in Proc. IEEE Appl. Power Electron. Conf., 2009.

[3] K. Zaghib et al., “Safe and fast-charging Li-ion battery with long shelf life for power applications,” J. Power Sources, 2011.

[4] 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., 2005.

[5] 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., Dec. 2010.

[6] 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., Jun. 2011,

[7] H. Min et al., “Research on the optimal charging strategy for Li-ion batteries based on multi objective optimization,” MDPI Energies, 2017.

[8] F. Leng, C. M. Tan, and M. Pecht, “Effect of temperature on the aging rate of Li-ion battery operating above room temperature,” Nature Sci. Rep., 2015.