2011 International Conference on Information and Intelligent Computing
IPCSIT vol.18 (2011) © (2011) IACSIT Press, Singapore

A Review on Li-Ion Battery Charger Techniques and Optimize Battery Charger Performance by Fuzzy Logic

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Abstract. In this paper lit-ion battery charger techniques of the past years are reviewed and we present different Li-Ion battery chargers and compare them to optimize the efficiency, speed up Li-Ion battery chargers and reducing damage of battery during the charging process and Some recent designs are discussed and the results are compared .Two methods are found out that follow above **characteristics**, and combining of them can optimize our battery charger in best way. According to results of comparison, the fuzzy control charging system can shorten the charging time with higher efficiency and lower temperature rise. In other hands Another experiment has been done to submit and prove optimal Li-ion battery charging frequency by using AC impedance technique that means if the battery charged by the optimal charging frequency fZmin the charging time and charging efficiency are improved, thus applying fZmin can improve the speed, life cycle of battery and the efficiency of fuzzy logic based charging method more than 96.623%.

Keywords: Li-Ion Battery charger, CV-CC, Fuzzy logic, fZmin

1. Introduction

Nowadays, the portable electronic devices have become the main applications of advanced technical products and become more popular devices like mobile phones, laptops, and MP3 players so the rechargeable batteries become an important and essential power source also the battery charging technique becomes more important. A single Li-Ion cell voltage is equal to three Ni-Cd or Ni-MH cells with the same weight and volume. High energy density and low self-discharge have always been keys to the Li-Ion's success in the market. The battery charger must have most efficiency, fast charging mode, and guarantee the safe of battery from probably damage of undercharge or overcharge and the cost must be reasonable.

The basic essential item designer of battery should have to check included factor, voltage, energy density, temperature performance, drain rate, and cycle life and it must have minimize size and weight and no memory accumulation .Battery life is also one of important properties. Rechargeable battery life is relation not only charger times [3, 4, 5,12,13], But overcharging control and charger way [1,2,6,10,11,16]. We must submit some battery charger with best efficiency [1, 2, 15, 5-10,18,19,20] and more safe from damage of overcharging or under charging. The life cycles of Li-Ion batteries are simply is influenced by overcharge or undercharge, because overcharge can damage the physical elements of the battery and undercharge can decrease the energy capacity of the battery. The Charger controller has duty of creating a feasible electro power for rechargeable battery and it must identify the point that is stopping charging to avoid rechargeable battery explosion [1,2,6,9,10]. The Constant-Current and Constant-Voltage (CC-CV) is used most broadly [1-4,6,7,9,10,11,13] but its function is cannot give the customer all of their need. Therefore, the fuzzy control, are applied to approach better battery charging performance [11,20,17]. The application of these intelligent techniques in designing is quiet complicated and costly but their efficiency are increased and also the damage will be decreased. We have submitted the usage of the fuzzy logic approach a fast smart Li-ion battery charger.

The most troubles, which happen usually with that charger, are the big charging current. It is important; an overcharging of minimum one minute can collapse the battery. And also when the temperature goes up the damage on life cycle of battery will increase. In general, better charging efficiency will result in longer battery cycle life because more charging efficiency can lead to lower power loss and lower temperature rise. Another advantage of using the fuzzy logic is the fact that the software execution of complex systems is not computer intensive**.** On the other hand phase-locked-loop technique is submitted to design a PLL based battery charger to achieve the purpose of good performance and low cost [5,14]. When the battery charger is designed with switching mode power supply (SMPS) converters, the passive elements are too huge to put them into the chip. Also, the battery chargers based on the switched-capacitor (SC) topology have the same problem, so the performance of power efficiency is not as good as expected. There are some previous works designed with the architecture of low dropout (LDO) voltage regulator. The major problem of many chargers is low power efficiency in the initial process [6, 10].

In this paper, Sections 2 present recent battery charging techniques, respectively. Section 3 shows the comparison table and evaluates the specifications and real test data of different techniques. Section 4 is the discussion and result through real test data and Section 5 is conclusion.

2. Charging Techniques

2.1. Constant current-Constant voltage (CC-CV) based techniques:

The HCC that is hysteresis-current-controlled buck converter feasible for Li-Ion battery charger is implemented in portable systems and applies the adopted technique of using CC-CV dual mode, based on internal resistance of Li-Ion battery [1]. This technique improved life cycle of Li-Ion battery and reached the better charger power efficiency. This method has improved the efficiently up to 82% under the average power of 825(mw).

Another technique is charge-pump based charger is operate in constant current-constant voltage (CC-CV) dual mode using small-scaled chips structure [2]. This strategy applies basic operations with current and voltage detection, end of charge detection and automatic charging speed control. This charger uses mixed method and it is supported from trickle/large CC to CV mode with charging rates that are different using 5 v power supply is and over or equal to 4.2V output voltage and uses maximum charging current that reaches to 700mA. The power efficiency in this case is 67.89%.

Another BRC method has decreased charging time of the Li-Ion battery and made it fast [3,4]. According to the internal parasitic resistance of the Li-Ion battery pack system, without fully charging the cell to the rated voltage value, the charger circuit switches from the CC stage to the CV stage. Degrading current at the CV stage causes the longer the charging time. Dynamic estimate the internal resistance of the battery pack system is possible by this proposed technique due to enlarge the period of the CC stage to achieve faster charging response. The period of the CC stage may increase to 40% that of the original design in practice. The operational mode of charger is dependent on the internal resistance of battery and it is affective for reducing the damage of Li-Ion battery and improves the power efficiency of charger [1-4].

There is other technique that designed to achieve maximum capacity, life span, and therefore runtime is presented and verified by experimental results [7]. This strategy uses a diode to switch continuously between two control a single power MOS device and high-gain linear feedback loops, automatically using constant charging the battery current and then constant voltage. , For decrease losses and achieving up to 27% better overall power efficiency an adaptive power-efficient charging scheme in the form of a cascaded switching regulator supply is applied which ensures the voltage across the charging power-intensive pMOS is kept low. Several Li-Ion batteries were charged by an 83% power-efficient circuit within 0.43% of their optimum full-charge voltage and therefore within a negligibly small fraction of their full capacity. also In reference [9]the most important advantage of High-frequency resonant over the traditional hard switching converters is that it offers higher power solidity and lower switching loss . The experimental results show the switching on and off of the main switches in a solar energy battery charger with a zero-voltage-switching resonant converter increases the overall circuit efficiency to 80%.

A high-efficiency multimode Li–Ion battery charger with variable current source and controlling previous-stage uses variable current source to achieve the goal of constant-current mode to charge the battery and control previous-stage supply voltage which increased the efficiency of the multimode battery charger [6]. In addition, this charger uses the adopted charging mode by two types of dual-mode strategy decided by the value of the equivalent series resistance of the Li–Ion battery. This strategy increases the Li–Ion battery life cycle. The designed Li–Ion battery charger is 0.35-μm CMOS double-poly four-metal processes. The charger works in good condition and the theoretical analysis can be confirmed according to the experimental results. Also up to 91.2% efficiency of the multimode Li–Ion battery charger can be achieved under the average power of 1.24W. The adaptive reference voltage accuracy is up to 97.3%.

An Area and Power-Efficient Analog Li-Ion Battery Charger Circuit [15] uses the tanh function of a sub threshold operational trans conductance amplifier to switch softly between constant-current and constant-voltage charging modes without adding circuit which consumes area and power. The need for precision- sense resistors in either the charging path or control loop is negated by current-domain circuitry for end-of-charge detection. And in In Design considerations for a contactless electric vehicle battery charger, the design concentrates the achievement to guarantee power transfer over the total operating range of the system. a new achievement to the design of the main resonant circuit is submitted, thus deviations from design outlook in order to phase or frequency shift are minimized[8].

The method of reference [19]is used in medical embed applications as a extremely integrated wirelessly powered battery charging circuit for small lithium (Li)-ion batteries which are rechargeable battery. This reference uses an inductive link and integrated Schottky barrier rectifying diodes, In order to cut out the dc signal from a power carrier though providing low forward voltage fall for better efficiency. This battery charger utilizes a new control method which relaxes comparator resolution necessities, and submitted simultaneous operation of CC and CV loops, and remove the external current sense resistor. In other proposed Li-Ion battery charger with the [18], the charging circuit permits charging voltage of 4.2V, big constant current of 312mA and trickle current of 150mA. For battery guard a thermal protection and over charging current and voltage protection are used. The power efficiency of this method is proposed in table 1.its noticeable that references [21-27] can be used in battery chargers technique.

2.2. Detecting of Optimal Li-ion Battery Charging Frequency by Using AC Impedance Technique:

In the Detecting of Optimal Li-ion Battery Charging Frequency by Using AC Impedance Technique some experiments has been done to submit and prove optimal Li-ion battery charging frequency by using AC impedance technique for SONY 18650 2000mAh battery. Different charging frequency results in different battery AC voltage and AC impedance of battery actually changed by different charging frequency. Experiments show that the optional Li-ion battery charging frequency is the minimum Ac impedance frequency fZmin. In this situation, the battery charged by the optimal charging frequency, the charging time and charging efficiency are improved above 30.68% using the fZmin [5].

In this method, authors investigate on the optimal Li-ion battery charging frequency by analyzing the relationship between the AC impedance of a battery and its charging performance. Experimental result shows that the charging time and the charging efficiency are improved by using pulse charging with f Zmin (the minimum AC impedance frequency) which in SONY 18650 2000mAh battery is 2 KH.So in this type, the charging frequency relates to the battery charge time and the charging capacity and also in f Zmin the loss in the Z battery is minimized and then the charged energy is maximized so, the battery charging efficiency will be improved.

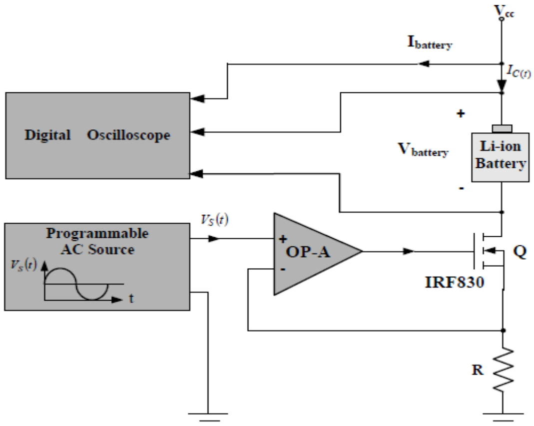

Figure 1. Optimal frequency battery charging platform. The switch can apply the optimal frequency to the circuit

TABLE I. EXPERIMENT DATA BY APPLYING OPTIMAL FREQUENCY METHOD. COMPARING CHARGING TIME, CHARGING CAPACITY ,DISCHARGE TIME, DISCHARGE CAPACITY AND EFFICIENCY IN DIFFERENT FREQUENCY WHICH THE BEST FREQUENCY IS 2 KHZ TO ARCHIVE HIGH EFFICIENCY [5]

Frequency	50Hz	500Hz	2KHz	5KHz	8KHz
Charging Time (min)	115	117	88	128	131
Charging Capacity (Ah)	1.916	1.95	1.467	2.13	2.18
Discharge Time (min)	41	40	41	41	40
Discharge Capacity (Ah)	1.366	1.333	1.366	1.366	1.333
Efficiency (%)	71.29	68.35	93.11	64.13	61.15

If the battery charged by the optimal charging frequency fZmin (the minimum AC impedance frequency) the charging time and charging efficiency are improved. The charging time and charging efficiency are improved above 30.68% using the fZmin. As result this battery charger is high efficiency, fast Li-Ion battery chargers and can reduce damage of battery during the charging process. The schematic and results are proposed in Figure 1 and Table I.

2.3. Fuzzy-Control-Based

- *Fuzzy applications*: One of the advantage of fuzzy logic controller is that,it could apply for non linear elements without finding exact mathematical model ,therefore we can apply fuzzy logic controller for battery charger system, because the lithium ion battery is a nonlinear element and has complex mathematical model, the fuzzy logic controller is suitable method to have better charging efficiency and also reduce the charging time without finding exact mathematical model. Recently advanced battery charging systems use the pulse current/voltage pattern Charging to obtain the evener distribution of ions in the battery electrolyte, attains to the Purpose of slowing down the polarization of the battery, and advances the charging speed and The cycle life. By applying fuzzy logic controller, we can reach to more efficient, low temperature charger, and reduce the charging time. fuzzy logic controller has control on the output current of battery charger while the current ,voltage and the temperature and of the charger and also the deviation of this values are the input of the fuzzy controller and the rules of controller are based on the change of this values .
- *Fuzzy-Control-Based Five-Step Li-Ion Battery Charger:* The proposed method that is shown in Figure 2 use the fuzzy control method to adjust the charger output current by using dsPIC[20]. The proposed charging system can shorten the charging time with higher efficiency and lower temperature rise. based on the fuzzy control law . The fuzzy logic controller can be categories into 4 different parts. The first one is Fuzzifier: fuzzifier means, uses the membership function for

converting the system values to linguistic fuzzy sets. Second is Fuzzy rule: The fuzzy rules can obtain from professional experience and the system control operation. Fuzzy inference engine: Fuzzy inference engine is an operating method that transforms the fuzzy rule base into fuzzy linguistic output; any rules can compound one fuzzy inference engine. Defuzzifier: the way that applies to converting the linguistic fuzzy sets to true values is defuzzifier. To achieve higher charging efficiency, a fuzzy controller is used to determine the charging current setting level. The fuzzy controller is calculated every 0.5 s. Figure 3 shows the block diagram of the implemented fuzzy controller. The input of the fuzzy controller is the temperature rise T and the deviation of temperature rise ΔT. Both T and ΔT are in triangular form. The singleton type used is to minimize the computational load of the microprocessor used in the proposed system.

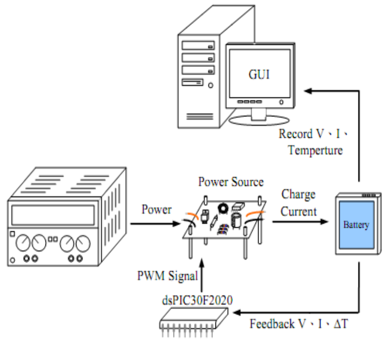

Figure 2. Block diagram of fuzzy logic charger .The voltage and current and the temperature are the input of the fuzzy logic and it set the PWM signal according to feedback signals [20]

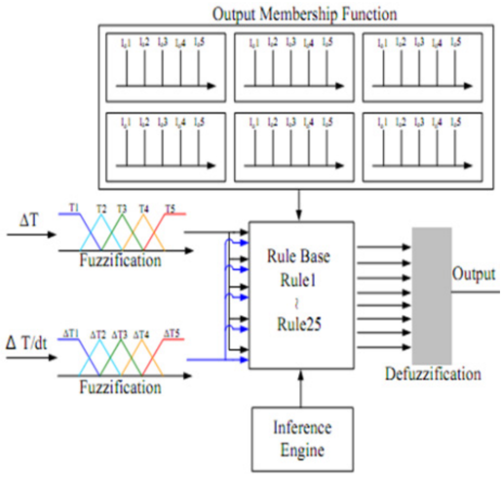

Figure 3. Block diagram of fuzzy logic controller. The temperature and the derivation of temperature are the input of the controller [20]

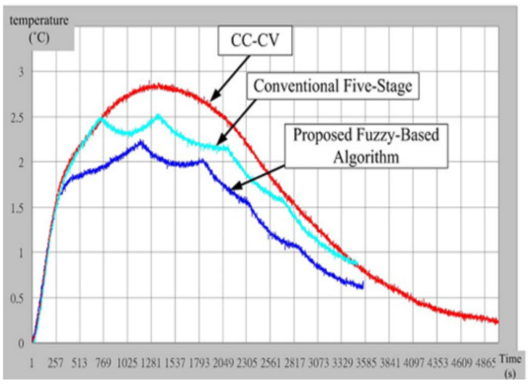

Figure 4. Temperature rise of three different charger methods .Comparing temperature rise of CC-CV method ,conventional five –stage method with proposed fuzzy logic [20].

It should be noted that five-step charging algorithm is employed in this method. Therefore, there are five groups of output membership functions. Each of the input variables T and ΔT is mapped into 5 different linguistic values. Therefore, the proposed fuzzy rule will consist of 25 different rules. The defuzzification method used in this reference is the commonly used center of gravity method. Figure 4.shows temperature rise of three methods.

3. Discussion and Result

We survey all of the ten methods and we find out that the best one for increasing the efficiency and reducing damage (due to negligible ripple output voltage voltage). Below table shows experiment data and specifications of all of charging technique for rechargeable li-ion battery. The power efficiency of fuzzy method [20] that is 96.623%, and it is better than the others one, and decrease temperature and increase life cycle of battery. According to the Table I results, by using fuzzy logic technique, there will be many advantages over the previous charger, which are: it has small rise temperature during charging process that results high charging efficiency, decreasing the charging time, it doesn't have any shut-offs during charging process, the life cycle will improve because of low temperature rise. Discharging process can be monitored and optimized in a similar way. Another advantage of using the fuzzy logic is the fact that the software implementation of complex systems is not computer intensive.

With Appling BRC technique the period of the CC mood can extend to about 40% that of the original design with a faster speed so the charging time can be decreased, so we can use it for speeding up the charging time of fuzzy logic method. In addition, according to optimal Li-ion battery charging frequency by using AC impedance technique, and if the battery charged by the optimal charging frequency fZmin (the minimum AC impedance frequency) the charging time and charging efficiency are improved[5]. Thus applying optimal charging frequency and fuzzy logic battery charger can propose new fuzzy logic battery charger with higher efficiency that will be more than 96.623% and faster and high protection battery with low temperature rise.

4. Conclusion

In this paper 10 charging method are proposed which the best one was five steps current setting based fuzzy logic controller. This proposed charger capable to charge the battery with higher efficiency and lower temperature rise comparing with other different method, because Using fuzzy technique can decrease temperature during charging period, that can increases charger efficiency and lead to quick charging, it won't be stop errors during charging, and the temperature range is decreased. In other hands Another technique that has submitted is optimal Li-ion battery charging frequency by using AC impedance technique that means if the battery charged by the optimal charging frequency fZmin the charging time and charging efficiency are improved, thus applying fZmin can improve the speed, life cycle of battery and the efficiency of fuzzy logic based charging method more than 96.623%, thus fuzzy method can be combine with Charging Frequency method by the optimal charging frequency fZmin in order to approach the better result will be investigated in future work.

TABLE II. COMPARISON OF TEN LI-ION BATTERY CHARGING METHODS TABLE. AMONG ALL OF THESE METHODS, THE ONE THAT APPLYING FUZZY LOGIC HAS THE HIGHEST EFFICIENCY. IN THIS METHOD THE FREQUENCY IS SET ON 50 KHZ TO REDUCE THE INPUT IMPEDANCE OF THE BATTERY DOWN TO THE MINIMUM VALUE. IN THE OTHER NINE METHODS, THE EFFICIENCY IS NOT MORE THAN 92%. THEREFORE IN THIS PAPER THE FUZZY LOGIC IS USED.

parameter	2006[1]	2007[10] & 2006 [2]	2007[9]	2005[8]	2006[7]	2009[6]	2011 [15]	2009 [20]	2007[19]	2004[18]
technology	TSMC 0.35 µm 2P4M	TSMC 0.35 µm 2P4M	NA	NA	AMI 0.5 µm technology	TSMC 0.35 µm 2P4M	AMI 0.5- m	Using Fuzzy in dsPIC	0.6 µm 3M-2P CMOS technology	TSMC 0 .3 5 2~P 4M CMOS
Power supply voltage	5 V or adaptive	5 V	24 V	3.9 V	2.7V-4.5 V	2.3V-4.5 V	4.3 V	NA	4.3 v	4.5 v
Average power consumption	825 mW	837mW	NA	NA	NA	1.24 W	NA	NA	NA	NA
Output voltage	4.2 V	4.2 V	10 V	2.5-4.2 V	2.5 V-4.2V	2 V-4.2V	4.2 V	NA	4.1 V	4.2V
Maximum switching frequency	1MHz	10 MHz	18 KHz	20 KHz	600KHz	100KHz	6.75 MHz	50 kHz	NA	NA
Maximum charging current	700 mA	694 mA	2 A	1 A	800 mA	698 mA	3 mA	NA	1.5 mA	312mA
Chip area(with PADs)	1.71x1.52mm2	1.455mm x 1.348 mm	NA	NA	NA	1.32 mm x0.95 mm	0.16 mm^2	NA	1.74 mm^2	Not specified
Average power efficiency	82%	67.89%	84%	55%	85%	91.2%	89.7%	high (96.623%)	73%	72.3%

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