Multilevel current charging system design and analysis for electric vehicles

1)KILLADA TARUN KUMAR , 2)PAKKI. MANOHAR, 3)CHATIKAM VARSHINI, 4)AMPOLU SARATH KUMAR, 5)PALLELA YUVA KISHORE, 6)PAKKI MURARI

1.Student, Electrical and Electrical Engineering , Sanketika vidhya parishad engineering college, Visakhapatnam, Andhra Pradesh

2.Student, Electrical and Electrical Engineering, Sanketika vidhya parishad engineering college, Visakhapatnam, Andhra Pradesh

3.Student, Electrical and Electrical Engineering, Sanketika vidhya parishad engineering college, Visakhapatnam, Andhra Pradesh

4.Student, Electrical and Electrical Engineering, Sanketika vidhya parishad engineering college, Visakhapatnam, Andhra Pradesh

5.Student, Electrical and Electrical Engineering, Sanketika vidhya parishad engineering college, Visakhapatnam, Andhra Pradesh

6.Head of the Department , Electrical and Electrical Engineering , Sanketika vidhya parishad engineering college, Visakhapatnam, Andhra Pradesh

ABSTRACT

Due to its higher energy density, longer lifespan, and superior power density, lithium batteries have emerged as the primary energy source for the development of electric vehicles (EVs) in recent years. Vehicles that run on batteries need to have their batteries charged quickly and effectively. While filling up a gasoline-powered car just takes a few minutes, charging an electric vehicle (EV) can take anywhere from four to six hours, depending on the C-rate. In this study, a two-wheeled electric vehicle's multicurrent charging mechanism is modelled and simulated. The suggested technique derives the charging current via a buck converter power conditioning circuit using a closed-loop control. The circuit is simulated in the MATLAB/Simulink environment to validate the suggested charging method. The results are then compared with those of the constant current (CC) and constant current-constant voltage (CC-CV) charging methods.

Keywords: *Lithium-ion batteries, electric vehicles, multi-current charging, constant current charging.*

I. INTRODUCTION

Serious ecological and human health issues are at the core of the massive global fleet of fossil fuel-powered automobiles. Conventional automobiles must be replaced with electric vehicles (EVs), hybrid electric vehicles (HEVs), and fuel cell electric vehicles (FCEVs). The primary energy source for these vehicles is a lithium-ion (Li) battery. Thus, to increase the use of electric vehicles, charging stations must be installed in strategic and easily accessible places. The most popular EV charging hub is made up of an isolated or non-isolated DC-DC converter that follows an AC-DC converter that meets power quality requirements [1] [2]. In developing the prototype for these EV charging stations, selecting the best power conditioning circuit, and minimising switching losses in controlled semiconductor devices are crucial steps.

Various C-rates can be used to charge batteries based on the situation. Normal ranges are [3]. Slow charge, in which the battery is charged between 0.1 and 0.5 degrees Celsius over the course of an overnight or 14–16-hour period. A quick charge takes three to six hours and uses 0.5C to 1C for charging. A fast charge is one that uses a charging rate more than 1C and is finished in less than an hour. Various battery charging techniques are used [4] [5].

II. CHARGING METHODS CONSIDERED FOR THIS STUDY

A.Constant Current Charging

With this charging technique, the battery's terminal voltage is increased to its completely charged level while the current supplied for charging the battery is maintained constant [6]. At this point, the battery's lifespan is shortened and overheating is caused by the constant current delivered to it. Together with SoC and power, the battery-pack terminal voltage progressively increases when a constant charging current is applied. The battery voltage can be viewed as its open-circuit voltage (OCV) when SoC hits 100%. In actuality, the voltage of the battery must be adjusted to its nominal value.

B. Constant Current-Constant Voltage (CC-CV) Charging

"Voltage Controlled Charging" is another name for this charging technique, which combines the CC and CV charging methods. With this method of charging, the battery voltage is not allowed to drop below a predetermined point (let us say 80% of its final value) before the charger pulls a continuous current from the mains supply [6]. After that, the terminal voltage is maintained at a steady level to progressively lower the current until the charging process is finished. The battery's parameter variation [7], [8] SoC, the sluggish chemical stabilisation process lowers the lithium-ion batteries' C-rate. Therefore, using this approach to quickly charge EV batteries is not recommended. Multiple level current charging techniques have been added to the CC-CV method to address the polarisation problem with batteries. This shortens the battery's charge time.

C. PROPOSED MULTILEVEL CURRENT CHARGING

To fully charge the battery in a shorter amount of time, the battery is charged at different constant current levels [9]. The Taguchi methodology, which describes the magnitudes of optimal current levels needed for multilevel battery charging, served as the model for this method [15]. The battery pack is charged in the first stage utilising the Constant Current method (CC), which involves continuously supplying current to the cell until its voltage reaches the upper threshold. The charging process stops when the cell crosses the higher threshold. We can charge a cell without voltage saturation by using this technique. The reduction in charging time and voltage stress on the battery is the main advantage of this technology. The control circuit is designed to measure the voltage and SoC of the battery being charged. The charging current is then adjusted from one level to another based on the measured values. This procedure is repeated until the battery is promptly fully charged without being overcharged. Three current levels are used in this experiment. According to more research, the multi-current approach may reduce cell deterioration while shortening charging times if current levels are adjusted during the process. These strategies are also driven by the desire to minimise heat production, stay out of situations that call for lithium plating, or lessen mechanical stresses in situations when lithium-ion diffusion is restricted and battery voltage is not overloaded.

The schematic depiction of the battery charger and its controls is shown in Fig. 1. Here, the suggested technique of charging the battery involves using the Buck converter in a current-controlled mode. The control circuit generates numerous reference currents depending on the voltage and energy level (SoC) of the battery pack that are gathered during the charging process with the aim of determining the battery's SoC level. The necessary converter output current is controlled by the PI controller. Fig. 2 shows the circuit topology for the Buck converter with perfect switches.

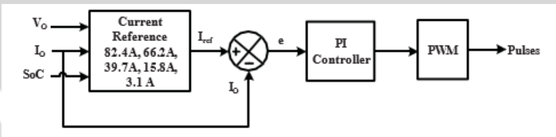

Fig.1 Schematic of the control circuit for the Battery Charger.

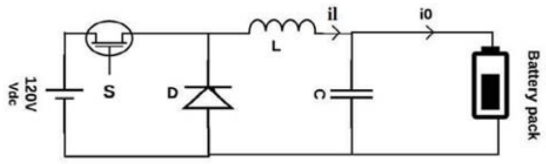

Fig.2 Buck converter topology used for the battery charger.

In this circuit [10], energy is periodically transmitted from the input to the output, where it is stored in capacitors and inductors for a portion of the time (while the switch is on) and used for the remainder. The input voltage of 1/D time equals the output voltage. The design equations in (1), (2), (3), and (4) are used to choose appropriate values for the capacitor and inductor. The converter is intentionally designed to function in continuous conduction mode (CCM) to reduce current ripple during charging. The controllable variable that alters the switch's ON time (t1) is the duty cycle of the PWM pulses. By varying the PWM signals' duty ratio, the control signal will alter the average current applied to the load. D, the duty cycle, is computed as follows:

$$\text{Duty Cycle } (D) = \frac{t_1}{T} \quad (1)$$

$$\text{Output voltage } (V_o) = V_c * D \quad (2)$$

$$\text{Inductance } (L) = \frac{(1-D)R_L}{2f} \quad (3)$$

$$\text{Capacitance } (C) = \frac{(1-D)V_o}{8V_o L f^2} \quad (4)$$

where f is the PWM pulse frequency and T = 1/f.

The symbols for output ripple voltage, output and input current, and ripple current are ΔVo, ΔIL, IO, and I.

The design of the charging circuit in this study considers the parameters of the Ather S340 (52V - 41.2Ah) electric two-wheeler battery pack [11]. It is thought that the charging station would rectify and filter the AC supply before providing the generated DC to the suggested onboard charger. The EV charger uses a Buck converter as a controlled current source. Users in this study have the option to select from a variety of current levels, as seen in Fig. 3, which is tabulated in Table I.

TABLE I. CHARGING CURRENT LEVELS

S. No	Charging Modes	Charging current
1	Slow Charging	20.1 A (0.5C)
2	Medium Charging	41.2A (1C)
3	Fast Charging	82.4 A (2C)
4	Multi Current charging	82.4A, 66.2A, 39.7A,15.8A,3.1A

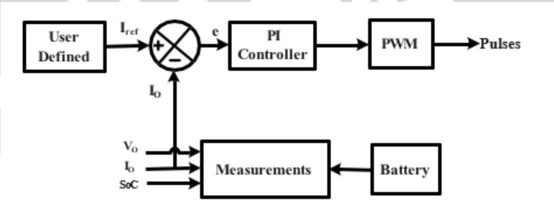

Fig.3: Schematic of the closed-loop control circuit for the Battery Charger.

II. PARAMETERS USED FOR THE SIMULATION STUDY

The charging procedures are analysed and tested for the following battery pack parameters from the Ather S340 electric two-wheelers.

1. A 41.2 AH, 2.2 kWh battery pack.

ii. 3350mAh and 4875mAh 3.6V Panasonic -18650 batteries.

iii. Voltage of the pack: 51.886 (52V).

A buck converter with the parameters listed in Table II is designed for the battery requirements provided.

TABLE II. BUCK CONVERTER SPECIFICATIONS

S.No	Components	Values
1	Input Voltage (V_{in})	120V
2	Output Voltage (V_{out})	60V
3	Switching Frequency (f_s)	50kHz
4	Inductor (L)	30mH
5	Capacitor (C)	50uF

In order to verify the effectiveness of the multilevel current charging method and compare it with the CC and CCCV ways of charging for the designated two-wheeler battery pack, simulation research is conducted using MATLAB SIMULINK, as shown in Fig. 4.

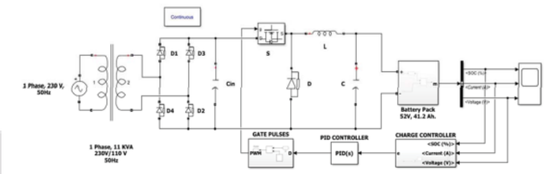

Fig. 4. Simulink model of the closed-loop control of battery charging.

IV. RESULTS AND DISCUSSION

This section provides a thorough analysis of the outcomes of various charging techniques along with a charging time comparison.

A. Constant Current Charging

The battery pack is charged in the first stage utilising the Constant Current method (CC), which involves continuously supplying current to the cell until its voltage reaches the upper threshold. The charging process stops when the cell crosses the higher threshold. This technique limits the impact of voltage saturation and allows for cell charging up to 80% [12], [13]. The suggested method's main advantage is that it can cut the charging time to less than an hour while putting less strain on the battery's voltage. As illustrated in Fig. 5 a and b this strategy achieves the maximum rated value for both the battery pack voltage and a constant current of 82.4A (2C). As illustrated in Fig., the battery reaches 80% of SoC at 1400s.

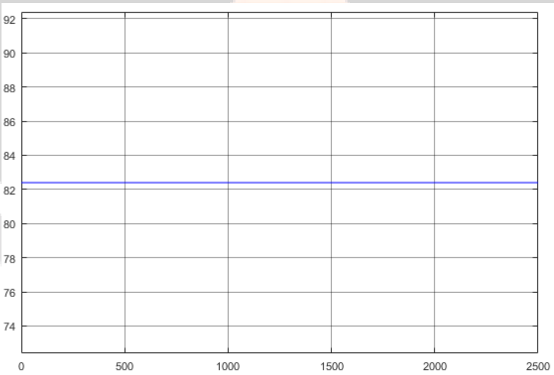

Fig5(a)current

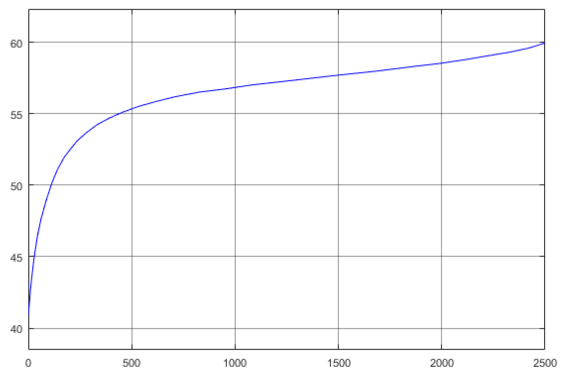

Fig. 5b Voltage(v) with respect to time

B. Constant Current Constant Voltage Charging (CC-CV)

This approach [14] begins charging at a rate of 2C (82.4A). Until the battery pack voltage hits its maximum onset value of 60V, as indicated in Fig. 7a&b, this current level is maintained constant. As illustrated in Fig. 7, the charging mode is changed to Constant Voltage (CV) charging mode once the battery pack voltage reaches its maximum onset value. The converter output voltage is maintained as the highest rated voltage for charging when using the CV technique. As illustrated in Fig. 7, the battery's current consumption drops dramatically in this charging mode until it reaches full charge. As Fig. 8 illustrates, the battery reaches 100% SoC in the 2400s.

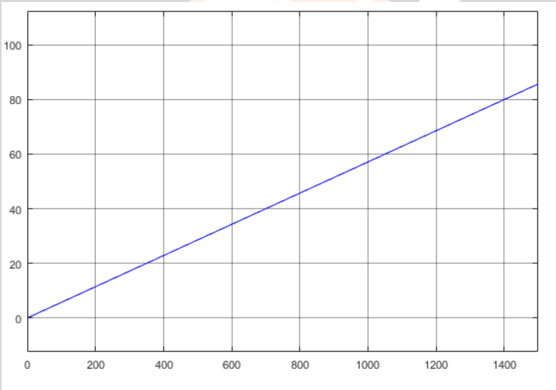

Fig. 6. SoC (%) vs Time(s) of the battery in CC charging.

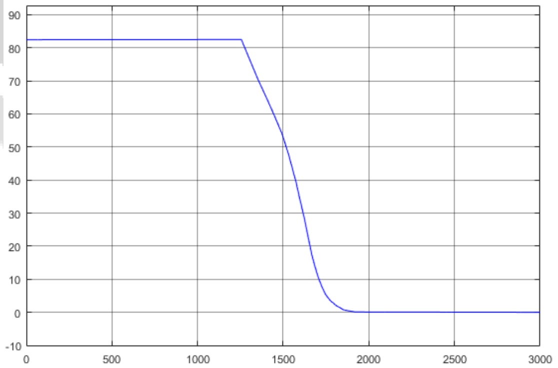

Fig 7a Current(I)

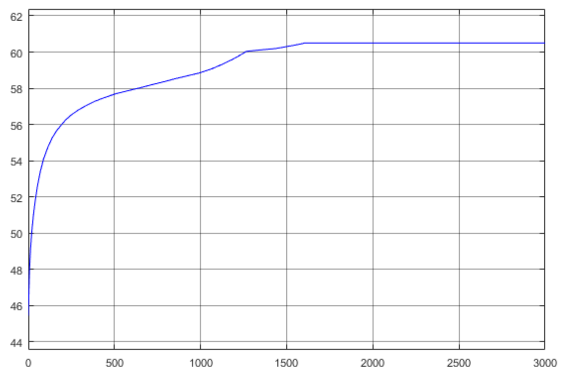

Fig 7b Voltage(V)

C. Multi-Level current Charging (MCC)

As illustrated in Fig. 9, the battery is charged using various current levels in the suggested charging technique, including 82.4A, 66.24A, and 39.7A. Figures 9&b and 10 depict the battery's matching terminal voltage and demonstrate that the battery reaches 100% SoC in the 2000s.

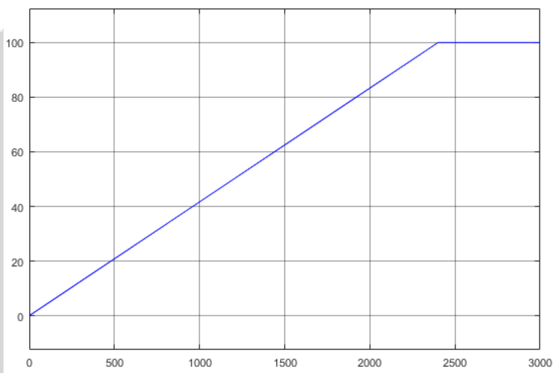

Fig. 8. SoC (%) vs Time(s) curve of battery CCCV charging.

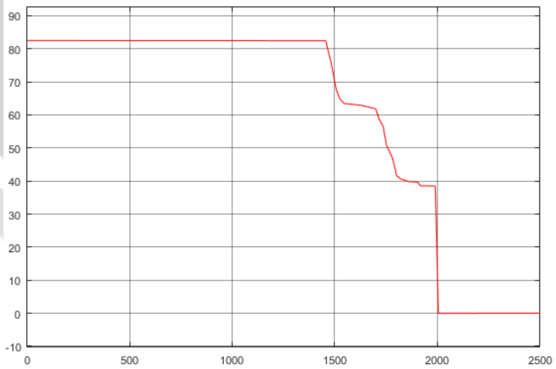

Fig 9a Current

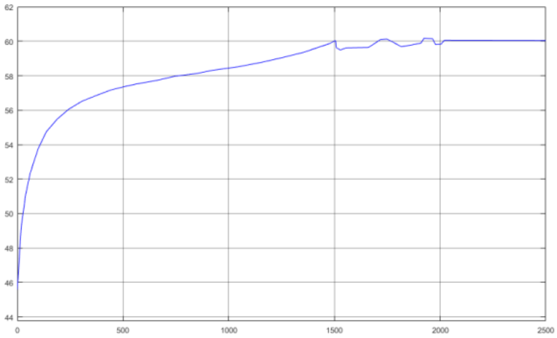

Fig9b Voltage

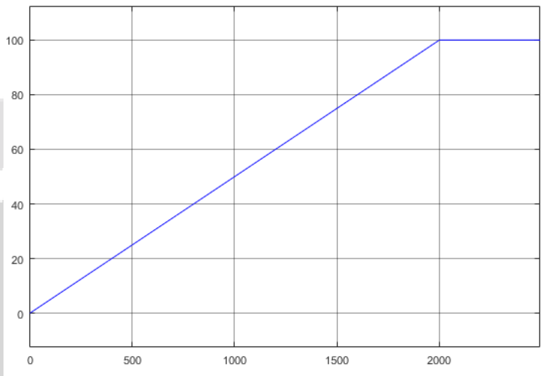

Fig.10. SoC (%) vs Time(s) during multi-level current charging of the battery.

Because the battery voltage is kept above the upper threshold voltage, overcharging is prevented and the battery is charged more quickly thanks to the multi-level current approach. As seen in Table it is contrasted with the traditional CC approach and the CC-CV method. III shows how long it takes to charge a battery using the CC, CC-CV, and multi-level current charging techniques. It is discovered that the CC-CV approach requires 2400s to fully charge, while multi-level charging requires approximately 2000s. The results clearly show that, in comparison to the CC-CV charging technique, the multi-level current charging approach speeds up charging and reduces the charging time by up to 16.67%.

TABLE III. CHARGING TIME AND SOC COMPARISON TABLE

S.No	*Charging Method*	*SoC (%)*	*Charging time(s)*
1	Constant Current(2C)	80	1400
2	CC-CV method	100	2400
3	Multi current	100	2000

D. CONCLUSIONS

This research presents a multi-level current based Li-ion fast charging mechanism. The suggested scheme's precise functioning, architecture, and performance attributes are contrasted with those of the CC and CC-CV charging techniques. The electric vehicle's dashboard allows the user to select the charging current level. A battery pack is charged to 80% capacity using CC charging. The battery takes 2400s (40 minutes) to completely charge using the CC-CV technique. On the other hand, the battery can be fully charged in the 2000s (33.33 minutes) with multi-level current charging. By lowering the stress on the battery, the suggested solution increases the battery's lifespan. Comparing this method to the CC-CV method, the saturation stage is removed and three-step current levels are substituted which requires roughly 2400s, a 16.67% decrease in charging time is seen. Multilevel current charging is valid as an onboard EV charger because, despite providing faster charging, the CC approach overheats the battery pack and shortens its lifespan.

REFERENCES

[1]. A. H. Jaafar, A. Rahman, A. Mohiuddin, and M. Rashid, “Modelling of an advanced charging system for electric vehicles,” in IOP Conference Series: Materials Science and Engineering, vol. 184, no. 1. IOP Publishing, 2017, p. 012023.

[2]. S. Khan, "Fast charging technique for lithium-ion cell," 2019.

[3]. X. Wu, W. Shi, and J. Du, "Multi-objective optimal charging method for lithium-ion batteries," Energies, vol. 10, no. 9, p. 1271, 2017.

[4]. Battery definitions, terms & terminology electronics notes. https: //www.electronics notes.com/articles/electronic components/battery- technology/terms-terminology definitions. php

[5]. Lithium-based batteries information-battery university, https://batteryuniversity.com/learn/article/lithium based batteries, (Accessed on 08/04/2019).

[6]. E. Ayoub and N. Karami, "Review on the charging techniques of a li-ion battery," in 2015 Third International Conference on Technological Advances in Electrical, Electronics and Computer Engineering (TAEECE). IEEE, 2015, pp. 50–55.

[7]. J. McDowall, "Understanding lithium-ion technology," Proceedings of Batticon, 2008.

[8] M. Team et al., "A guide to understanding battery specifications," 2008.

[9] multi-stage constant-current charging protocol for a high-energy- density pouch cell based on a 622ncm/graphite system rsc advances (Rs publishing)," https://pubs.rsc.org/en/content/articlelanding/2019/ra/c9ra03629f#!divAbstract,

[10] D. W. Hart, Power electronics. Tata McGraw-Hill Education, 2011.

[11] D. S. Gautam, F. Musavi, M. Edington, W. Eberle, and W. G. Dunford, "An auto- motive onboard 3.3-kw battery charger for phi application," IEEE Transactions on Vehicular Technology, vol. 61, no. 8, pp. 3466–3474, 2012.

[12] J. Liu, "Charge and discharge characterization of lithium-ion electrode materials through coin cell testing," Ph.D. dissertation, The Ohio State University, 2015.

[13] R. A. Bustos Bueno, "State of charge and parameter estimation of electric vehicle batteries," Ph.D. dissertation, 2018.

[14] S. Lacroix, E. Labour's, and M. Hilaire, "An integrated fast battery charger for electric vehicle," in 2010 IEEE Vehicle Power and Propulsion Conference. IEEE, 2010.

[15] Liu, Yi-Hwa, and Yi-Feng Luo. "Search for an optimal rapid-charging pattern for Li-ion batteries using the Taguchi approach." IEEE transactions on industrial electronics 57.12 (2009): 3963-3971.