Multilevel Current Charging for Electric Vehicles: Design and Analysis

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Abstract: Lithium batteries have emerged as the primary energy source for electric vehicles (EVs) in recent years due to its high energy density, superior power density, and extended lifespan. For cars that run on batteries, quick and efficient battery charging is essential. Fuelling a gasoline-powered vehicle takes a few minutes, while depending on C-rate, charging an EV takes four to six hours. In this study, a two-wheeled electric vehicle's multi-current charging mechanism is modelled and simulated. The suggested technique drives the charging current through a buck converter power conditioning circuit using a closed-loop control. The circuit is simulated in the MATLAB/Simulink environment to verify the suggested charging technique, and the outcomes are contrasted with that of the Constant Current-Constant Voltage (CC-CV) and Constant Current (CC) charging methods.

Keywords: Lithium-ion batteries, electric vehicles, constant current charging, and multicurrent charging

1.OVERVIEW

There are significant ecological and human health issues associated with the vast number of fossil fuel-powered automobiles in use worldwide. Conventional automobiles must be replaced with electric vehicles (EVs), hybrid electric vehicles (HEVs), and fuel cell powered electric vehicles (FCEVs). The primary energy source for these vehicles is lithium-ion (Li) batteries. Therefore, to increase the use of electric vehicles, charging stations must be placed in certain, easily accessible areas. The most popular EV charging station consists of an AC-DC converter [1] [2] that satisfies the necessary power quality requirements and and followed by a DC-DC converter, either isolated or non-isolated. The creation of these EV charging station prototypes relies heavily on selecting the best power conditioning circuit and minimizing switching losses in controlled semiconductor devices.

Depending on the needs, batteries can be charged at various C-rates. Normal values are [3]. Slow Charge: this type of charging takes place between 0.1 and 0.5 degrees Celsius and takes 14 to 16 hours or overnight to finish. Quick Charge takes three to six hours and uses 0.5C to IC for charging. A fast charge is one that is finished in an hour and has a charging rate higher than Is In practice, various battery charging techniques are used [4] [5].

II. CHARGE METHODS TAKEN INTO ACCOUNT FOR THIS STUDY

A. Continuous Charging with Current With this charging technique, the battery is charged with a steady current until the battery's terminal voltage reaches its full charge [6]. At this point, the battery's continuous current supply leads to overheating, which can harm the battery and shorten its lifespan. The battery-pack terminal voltage steadily increases along with the SoC and power when a set charging current is applied. The battery voltage can be viewed as its open-circuit voltage (OCV) after SoC reaches 100%. In actuality, the battery voltage must be controlled to reach its stated level.

B. Charging with Constant Current-Constant Voltage (CC-CV) "Voltage Controlled Charging" is another name for this charging technique, which combines various charging techniques, both CV and CC. Using this charging technique, the charger continuously takes power from the supply mains until the battery voltage hits a predetermined threshold, such as 80% of its ultimate value [6]. After that, the terminal voltage is maintained at a steady level, allowing the current to be progressively decreased until the charging process is finished. changes in battery characteristics [7].[8] SoC, this technique is not appropriate for rapid EV battery charging because the chemical stabilization process is too sluggish and restricts the C-rate of lithium-ion batteries. The CC-CV technique has been improved to address the problem of battery polarization by including multiple level current charging techniques, which shortens the battery's charging time.

C. SUGGESTED CURRENT MULTILEVEL CHARGING

Modify Your Styles Several steady current levels are used to charge the battery [9] so that it can be fully charged faster. 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 Constant Current technique (CC), which charges the cell by supplying a steady current until its voltage reaches the upper threshold, is used in the first stage of charging the battery pack. Charging stops when the cell crosses the higher threshold. This technique allows us to charge a cell without reaching voltage saturation. This method's main advantage is that it reduces the battery's charging time and voltage stress. The purpose of the control circuit is to obtain the battery's voltage and SoC. charged, and current is moved from one level to another according to the values obtained by the charging AVo. This procedure keeps on until the battery is promptly fully charged without being overcharged. Three current levels are used in this experiment. According to additional research, the multicurrent approach may restrict cell degradation while cutting down on charging times by varying the current levels during the charging process. Reducing heat generation, avoiding situations that call for lithium plating, or lowering mechanical stresses when lithium-ion diffusion is constrained and battery voltage is not overloaded are further reasons for such methods.

The schematic illustration of the battery charger and related controls is shown in Fig. 1. In the suggested method, the battery is charged by operating the Buck converter in a current-controlled mode. During charging, the control circuit is designed to determine the battery's state of charge (SoC) and creates multiple reference currents based on the voltage and energy level (SoC) of the battery pack. Controlling the necessary converter output current is done by the PI controller. The Buck converter's circuit topology with perfect switches is shown in Fig. 2.

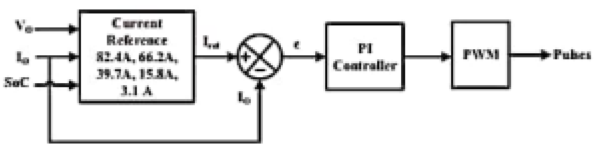
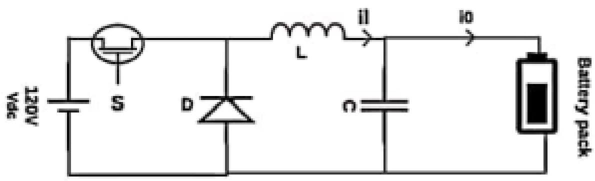


Fig.1 Schematic of the control circuit for the Battery Charger.

The battery charger's control circuit schematic is shown in Figure 1.



The battery charger's Buck converter topology is shown in Figure 2.

This circuit [10] periodically transfers energy from input to output, stores it in capacitors and inductors for a portion of the time (when the switch is on), and uses the remainder for other purposes. The input voltage for 1/D time is 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 designed to decrease the ripple current during charging by operating in continuous conduction mode (CCM).

The controlled variable, the duty cycle of the PWM pulses, affects the switch's ON time (tl). The control signal will manage the load's average current. by altering the PWM signals' duty ratio. D, the duty cycle, is computed as follows:

Duty Cycle (D) = (1) V D is the output voltage (V).

(2) L is the inductance, and (1-D)RL 2f

(3) (1-D)V 8VLf2 = Capacitance (C)

(4) where AVO, AIL, IO, and I stand for output ripple voltage, output ripple current, and input and output current, and T I/f and f are the PWM pulse frequencies.

The charging circuit design in this study takes into account the parameters of the Ather S340 (52V 41.2Ah) electric two-wheeler battery pack [11]. It is thought that the planned onboard charger would receive the DC generated by the charging station's rectification and filtering of the AC feed. The EV charger's controlled current source is a Buck converter. Users can select from a variety of current levels in this study, as illustrated in Fig. 3 and recorded in Table. I.

Current Table of Charge Levels

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

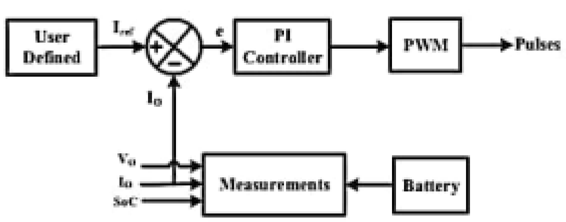


Figure 3: Diagram of the battery charger's closed-loop control circuit.

III. THE SIMULATION STUDY'S PARAMETERS

The charging techniques are simulated for the following battery pack specifications from the Ather S340 electric two-wheelers in order to conduct testing and analysis. 2.2kWh, 41.2Ah battery pack, for example.

ii. Panasonic-18650 3350mAh, 4875mAh, 3.6V battery.

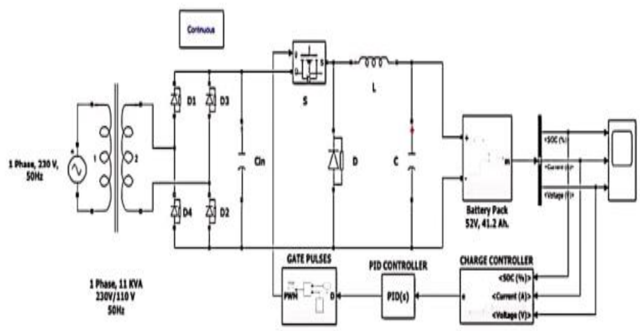
iii. Pack voltage: 52V, or 51.886.

The buck converter is developed with the parameters listed in Table II for the specified battery requirements.

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

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, a simulation analysis is conducted using MATLAB SIMULINK, as shown in Fig. 4.



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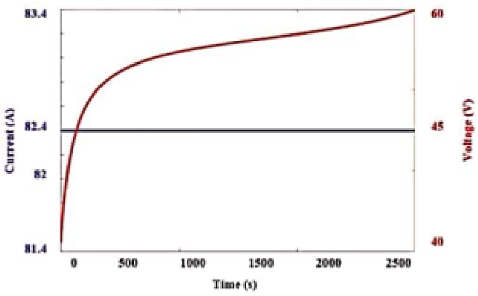
IV. OUTCOMES AND TALK

The outcomes of several charging techniques are thoroughly discussed in this section, along with a comparison of charging times.

A. Continuous Charging with Current

The Constant Current technique (CC) is used in the first step to charge the battery pack, where the cell is charged by supplying a steady current until the voltage crosses the upper limit. Charging stops when the cell crosses the higher threshold. This technique limits the impact of voltage saturation and allows us to charge a cell up to 80% [12], [13]. The main advantage of the suggested approach is that the battery will experience less voltage stress and the charging time can be shortened to less than an hour. Fig. 5 illustrates how the battery pack voltage approaches the maximum rated value while maintaining a steady current of 82.4A (2C). As seen in Fig. 6, the battery reaches 80% of SoC at 1400s.



83.4 Figure 5: Battery charging current (A) against battery charging time (s) in CC mode.

B. Continuous Current CC-CV, or constant voltage charging This approach [14] begins charging at a rate of 2C (82.4A). As illustrated in Fig. 7, this current level is maintained until the battery pack voltage hits its maximum onset value of 60V. 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 in the CV technique. As seen in Fig. 7, the battery's current drops significantly in this charging mode until it is fully charged. In the 2400s, the battery reaches 100% SoC as shows in the fig .8.

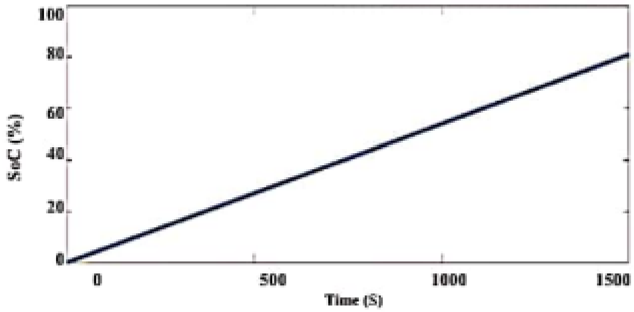


Figure .6. SOC (%) vs Time (s) of the battery in CC charging

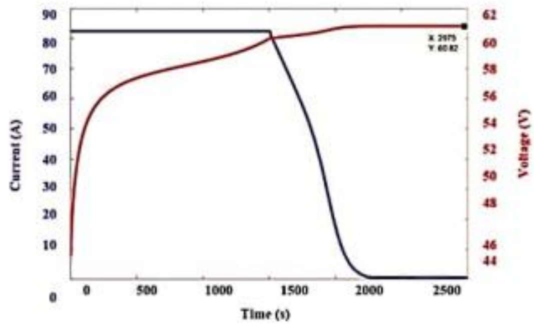


Figure 7 shows the battery's charging current (A) versus time (s) during CCCV charging.

C. MCC, or multi-level current charging

As seen in Fig. 9, the battery is charged using a range of current levels in the suggested charging technique, including 82.4A, 66.24A, and 39.7A. The appropriate terminal voltage of the battery is illustrated in fig.9andfig10 indicates that the battery attains 100%soc in the 2000s. Fig. 10. SoC (%) vs. Time(s) during the battery's multi-level current charging.

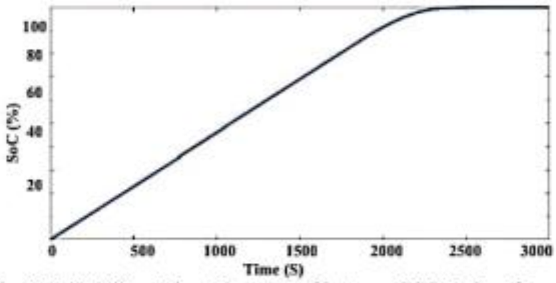


Fig. 8.SoC (%) vs Time(s) curve of battery CCCV charging.

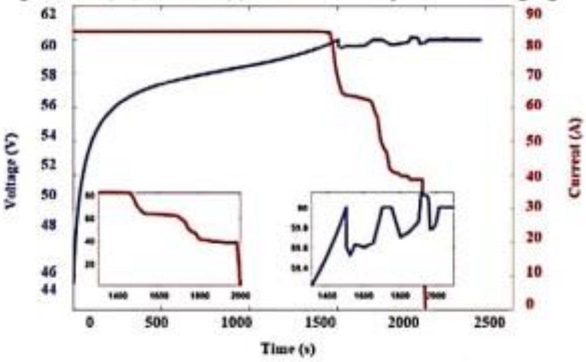


Fig.9. SoC (%) vs Time(s) during Multi-level current charging of the battery.

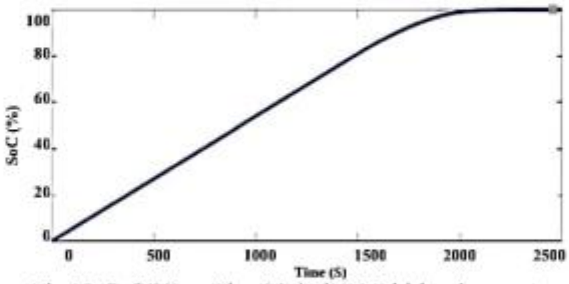


Fig.10. SoC(%) vs Time(s) during Multi-level current charging of the battery.

By keeping the battery voltage within the upper threshold voltage, the multi-level current approach prevents overcharging and charges the battery more quickly. As illustrated in Figure 11 and the Table, it is contrasted with the traditional CC approach and the CC-CV method.III shows how long it takes to charge the battery. through multi-level current charging, CC, and CC-CV techniques. While multi-level charging takes around the 2000s, the CC-CV method's charging time is determined to be around the 2400s. The results clearly show that, in comparison to the CC-CV charging method, the multi-level current charging approach speeds up charging and reduces charging time by up to 16.67%.

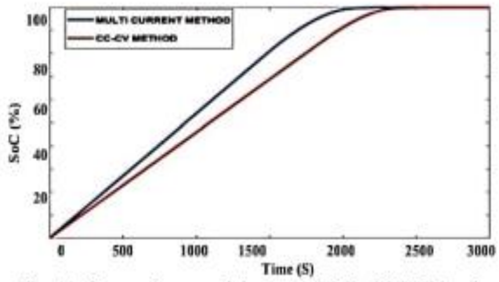


Fig. 11. Comparison graph between SOC of CC-CV and multicurrent method

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

V. FINAL RESULTS

This paper presents a fast Li-ion charging method based on multi-level current. The suggested scheme's performance, design, and operating details 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. The battery pack is 80% charged via CC charging. The charging process in the CC-CV technique the battery takes 40 minutes to completely charge in the 2400s. In contrast, the battery can be fully charged in the 2000s (33.33 minutes) using multi-level current charging. By lessening the strain on the battery, the suggested technique increases its lifespan. This method reduces the charging time by 16.67% compared to the CC-CV method, which takes around 2400s, by doing away with the saturation stage and substituting three-step current levels. Multilevel current charging is validated as an onboard charger for EVs even though the CC approach speeds up charging but shortens battery pack life by causing overheating.

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