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Optimizing EV Charging Infrastructure: A Comparative Study of CC and CC-CV Methods

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Abstract: The development of Electric Vehicles (EV) has seen lithium batteries emerge as the primary energy source in recent years, owing to their peak energy density, enhanced power density, and extended lifespan. Rapid and efficient battery charging is essential for electric vehicles. While it takes only a few minutes to refuel petrol-powered vehicles, an EV requires 4-6 hours for a full charge, depending on the C-rate. This paper discusses the modeling and simulation of a multi-current charging method designed for a two-wheeled electric vehicle. The proposed approach employs a closed-loop control system to regulate the charging current via a buck converter power conditioning circuit. To assess the effectiveness of the proposed charging method, the circuit is simulated within the MATLAB/Simulink environment, and the results are compared to those obtained from the constant current charging (CC) method and the Constant Current-Constant Voltage (CC-CV) charging method.

I. INTRODUCTION

The extensive presence of fossil fuel-powered vehicles globally has led to significant ecological and human life challenges. To address this, Electric Vehicles (EVs), Hybrid Electric Vehicles (HEVs), and Fuel Cell Electric Vehicles (FCEVs) should be adopted as alternatives to traditional vehicles, with the Lithium-Ion (Li) battery serving as the primary energy source for their operation. Therefore, it is essential to establish charging stations in specific and accessible locations to promote the adoption of electric vehicles. A typical EV charging hub consists of an AC–DC converter [1] [2] that meets the necessary power quality standards, followed by either an isolated or non-isolated DC-DC converter. Selecting the most effective power conditioning circuit and reducing switching losses in controlled semiconductor devices are critical factors in the prototype development of these EV charging stations. Batteries can be charged at various C-rates based on specific requirements. Typical levels include [3] Slow Charge, where the charging occurs at a rate of 0.1C to 0.5C, taking approximately overnight or 14-16 hours to fully charge. Quick Charge refers to a method that utilizes a rate of 0.5C to 1C, requiring about 3 to 6 hours for completion. Fast Charge is characterized by a charging process that is finished within an hour, employing a rate exceeding 1C. Various battery charging methods are implemented in practice [4] [5].

II. CHARGING METHODS CONSIDERED FOR THIS STUDY

Constant Current Charging

In this charging technique, the current provided for battery charging remains constant until the terminal voltage of the battery increases to its fully charged state[6]. The continuous current delivered to the battery during this phase can lead to overheating, which may cause damage and reduce the battery's lifespan. As a fixed charging current is applied, the terminal voltage of the battery pack gradually increases in conjunction with the state of charge (SoC) and power. Once the SoC reaches 100%, the battery voltage can be observed as its open-circuit voltage (OCV). In fact, it is necessary to regulate the battery voltage to its nominal level.

Constant Current-Constant Voltage (CC-CV) Charging

This charging technique is referred to as "Voltage Controlled Charging" and combines both CC and CV charging methods. In this approach, the charger maintains a constant current from the supply mains until the battery voltage attains a specific level (approximately 80% of its final value) [6]. Subsequently, the terminal voltage is held steady, allowing the current to decrease gradually until the charging process is complete. The fluctuation of battery parameters [7],[8] SoC, The chemical stabilization process is relatively slow, which restricts the C-rate of Lithium-ion batteries, making this method

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unsuitable for rapid charging of EV batteries. To address the issue of battery polarization, the CC-CV method has been enhanced by incorporating multiple level current charging schemes, thereby reducing the battery charging time.

PROPOSED MULTILEVEL CURRENT CHARGING

The battery is charged using various constant current levels [9] to achieve complete charging in a shorter duration. This method draws inspiration from the Taguchi approach, which elucidates the magnitudes of optimized current levels necessary for multilevel battery charging[15]. Initially, the battery pack undergoes charging through the Constant Current method (CC), wherein the cell is charged by applying a constant current until its voltage attains the upper threshold. Once this upper threshold is reached, the charging process is halted. This technique allows for cell charging without experiencing voltage saturation. A significant advantage of this method is the reduction in both charging time and voltage stress on the battery. The control circuit is designed to monitor the State of Charge (SoC) and voltage of the charging battery, and based on the collected data, the charging current is adjusted from one level to another. This procedure persists until the battery is swiftly fully charged without the risk of overcharging. In this study, three current levels are implemented. Further research indicates that in the multi-current method, modifying the current levels throughout the charging process can mitigate cell degradation while also shortening charging times. Such strategies are further driven by the need to minimize heat generation, prevent conditions that could lead to lithium plating, and reduce mechanical stresses when lithium ion diffusion is constrained, ensuring that the battery voltage does not exceed safe limits. Figure 1 illustrates the schematic layout of the battery charger along with its related controls. In this setup, the Buck converter functions in a current-controlled mode to charge the battery as per the proposed method. The control circuit is designed to monitor the State of Charge (SoC) level of the battery during the charging process, generating multiple reference currents based on the measured voltage and energy level (SoC) of the battery pack. The PI controller is responsible for regulating the necessary output current of the converter. The circuit topology for the Buck converter, featuring ideal switches, is depicted in Figure 2.

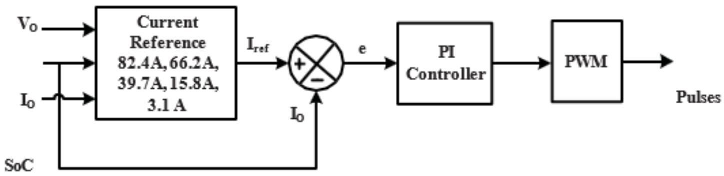

Fig.1 Schematic of the control circuit for the Battery Charger.

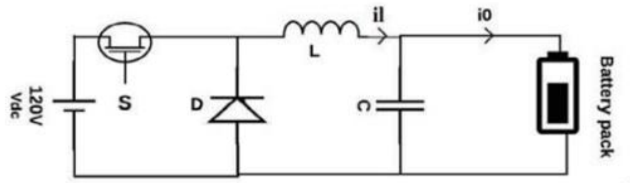

Fig.2 Buck converter topology used for the battery charger.

In the circuit [10], energy is transmitted periodically from the input to the output, where it is stored in inductors and capacitors during a fraction of a period (when the switch is activated), and utilized in the remaining fraction. The output voltage corresponds to the input voltage multiplied by 1/D time. The design equations for determining appropriate values for the capacitor and inductor are provided in equations (1), (2), (3), and (4). The converter is designed to function in continuous conduction mode (CCM) to reduce ripple current during the charging process. The duty cycle of the PWM pulses serves as the controlled variable, which adjusts the ON time (t1) of the switch. The control signal will manage the average current supplied to the load by modifying the duty ratio of the PWM signals. The duty cycle, D, is calculated as:

Duty Cycle $(D) = \frac{t1}{}$ (1)

Output voltage $(V_O) = V_C * D$ (2)

Where T = 1/f and f is the frequency of PWM pulses ΔVo, ΔIL, IO and I, represent output ripple voltage, ripple current, output and input current. In this research, the specifications of the Ather S340 (52V - 41.2Ah) electric two-wheeler battery pack are taken into account for the design of the charging circuit [11]. It is assumed that the rectification and filtering processes will be carried out at the charging station, and the resulting DC will be supplied to the proposed onboard charger. A Buck converter is utilized as a controlled current source within the EV charger. In this study, users have the

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option to select various current levels, as illustrated in Fig. 3 and detailed 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

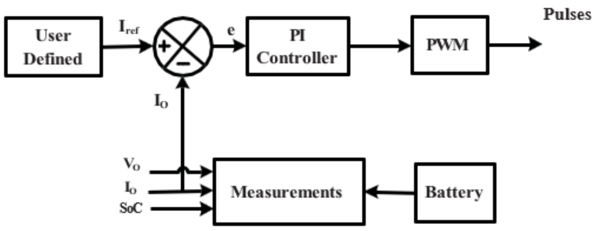

Fig.3: Schematic of the closed-loop control circuit for the Battery Charger.

III. PARAMETERS USED FOR THE SUMULATION STUDY

For testing and analysis, the charging methods are simulated based on the specifications of the battery pack used in the Ather S340 electric two-wheelers.

I. 2.2kWh, 41.2Ah battery pack.
II. Panasonic -18650 Battery, 3350mAh, 4875mAh 3.6V.
III. Pack voltage: 51.886 (52V).

For the given battery specifications buck converter is designed with parameters as given in Table. II

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

The simulation study was conducted utilizing MATLAB SIMULINK, as illustrated in Fig. 4, to assess the effectiveness of the multilevel current charging technique. This method was compared with the CC and CCCV charging methods for the designated two-wheeler battery pack.

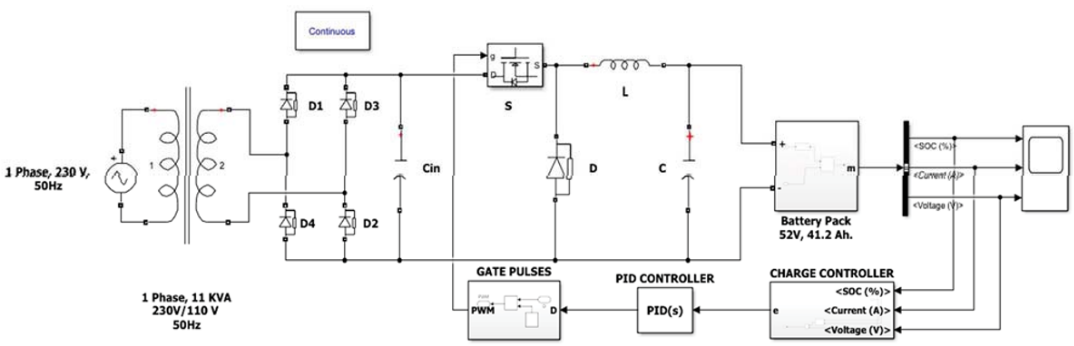

Fig. 4. Simulink model of the closed-loop control of battery charging.

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IV. RESULTS AND DISCUSSION

In this section, a comprehensive analysis of the results pertaining to different charging methods is presented, along with a comparison regarding charging time.

Constant Current Charging

In the initial phase, the battery pack undergoes charging through the Constant Current method (CC), wherein the cell is charged by applying a steady current until its voltage attains the upper limit. Once the cell hits this upper limit, the charging process is halted. This approach allows for charging a cell up to 80%, while also mitigating the effects of voltage saturation [12],[13]. A significant advantage of the proposed method is that it can reduce the charging duration to under an hour, while exerting less voltage stress on the battery. In this process, a constant current of 82.4A (2C) is utilized, and the battery pack voltage reaches its maximum rated value, as illustrated in Fig. 5. The battery achieves 80% State of Charge (SoC) at 1400 seconds, as depicted in Fig. 6.

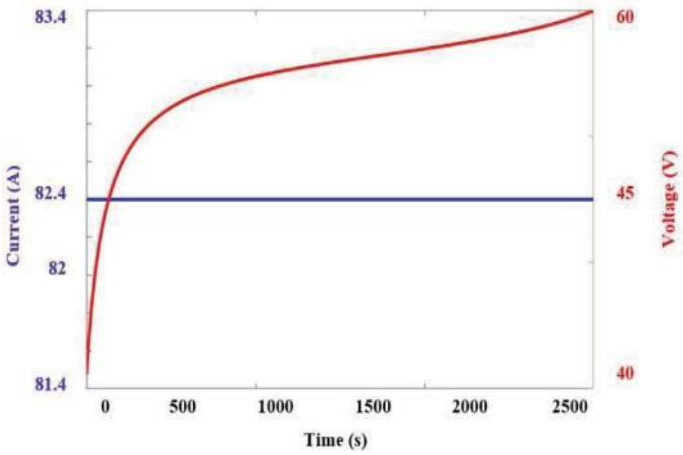

Fig. 5. Charging current (A) vs Time(s) of the battery in CC charging.

Constant CurrentConstant Voltage Charging (CC-CV)

In this approach [14], the charging process commences at a rate of 2C (82.4A). This current level is maintained consistently until the voltage of the battery pack reaches its peak onset value of 60V, as illustrated in Fig. 7. Once the battery pack voltage reaches this maximum onset value, the charging mode transitions to Constant Voltage (CV) mode, as depicted in Fig. 7. During the CV method, the output voltage of the converter is held at the maximum rated voltage for charging. In this charging mode, the current drawn by the battery diminishes exponentially until it is fully charged, as shown in Fig. 7. The battery achieves a 100% State of Charge (SoC) in 2400 seconds, as indicated in Fig. 8.

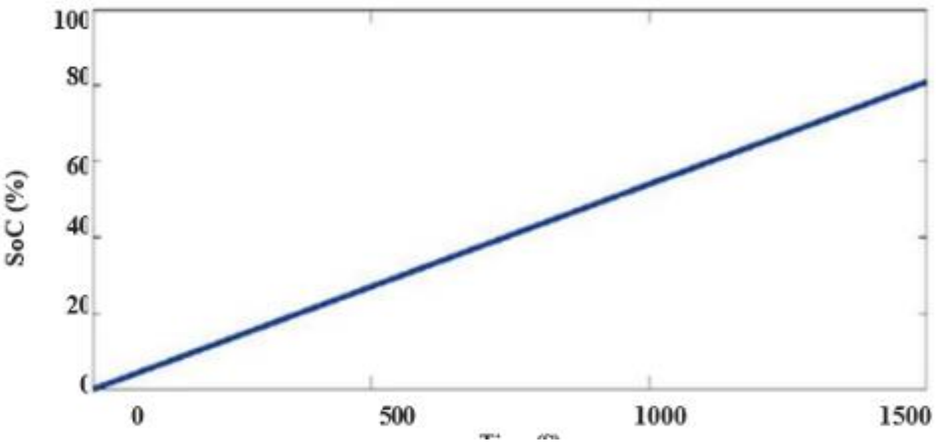

Fig. 6 Soc(%) vs Time(s) of the battery in CC charging.

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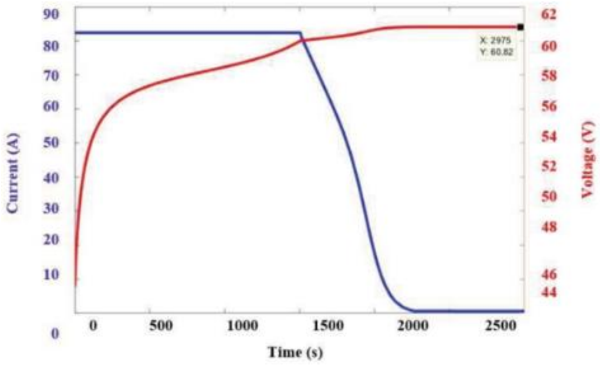

Fig. 7. Charging current (A) Vs Time(s) of the battery in CCCV charging.

Multi- Level current Charging (MCC)

In the suggested charging technique, the battery is charged using various current levels, including 82.4A, 66.24A, and 39.7A, as depicted in Fig.9. The associated terminal voltage of the battery is represented in Fig.9, while Fig.10 demonstrates that the battery reaches a 100% State of Charge (SoC) within the 2000s.

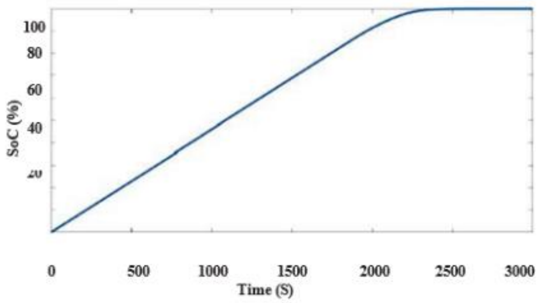

Fig. 8.SoC (%) vs Time(s) curve of battery CCCV charging.

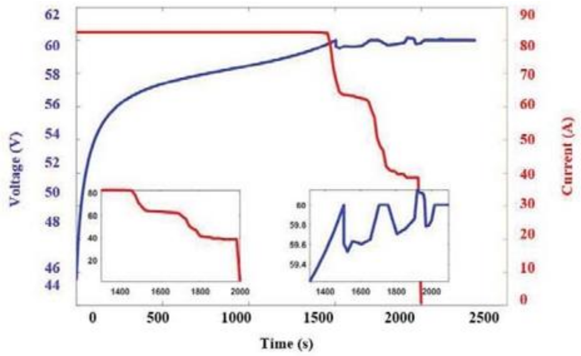

Fig.9. SoC (%) vs Time(s) during Multi-level current charging of the battery.

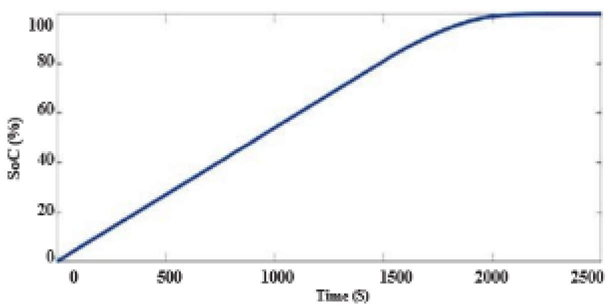

Fig.10. SoC (%) vs Time(s) during Multi-level current charging of the battery.

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Consequently, utilizing the multi-level current method allows for a more rapid charging of the battery while preventing overcharging by keeping the battery voltage within the upper threshold limit. A comparison is made with the traditional CC method and the CC-CV method, as illustrated in Fig.11, and Table.III outlines the duration required to charge the battery using the CC, CC-CV, and multi-level current charging techniques. The charging duration for the CC-CV method is recorded at 2400 seconds, whereas the multi-level charging method requires approximately 2000 seconds. The results clearly indicate that the multi-level current charging method enhances the charging speed and reduces the charging time by up to 16.67% when compared to the CC-CV charging method.

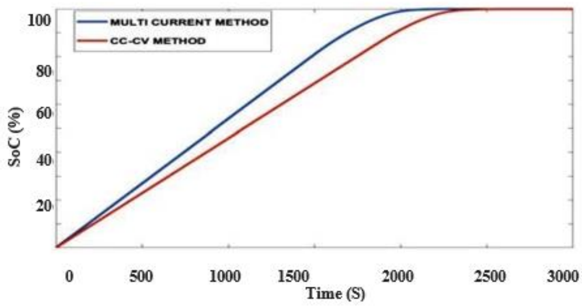

Fig. 11. Comparison graph between SOC of CC-CV and multicurrent method

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. CONCLUSION

A multi-level current based fast charging of Li-ion method is presented in this paper. The detailed operation, design, and performance characteristics of the proposed scheme are compared with CC and CC-CV charging methods. The user can choose the charging current level through the dashboard of the electric vehicle. By CC charging battery pack is charged up to 80%. In the CC-CV method, the charging time for fully charging the battery in the 2400s (40 mins). Whereas, by multi-level current charging the battery can be fully charged in the 2000s (33.33 mins). The proposed method reduces the stress on the battery and thus extends the battery life span. In this method saturation stage is eliminated and replaced with three-step current levels, when compared with the CC-CV method which takes about 2400s, a 16.67% reduction in charging time is observed. Though the CC method gives a faster charging it causes the overheating of the battery pack and reduces the life thus validates the multilevel current charging as an onboard charger of the EV.

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